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The Abrasiveness of Sheer Overlay Fabrics Used in Textile Conservation

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THE ABRASIVENESS OF SHEER OVERLAY FABRICS
USED IN TEXTILE CONSERVATION
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ABSTRACT

Fragile fabrics in textile collections are subject to deterioration due to use, exhibition, and improper storage conditions. Textile conservators often sew sheer fabrics as overlays directly over weakened fabrics to protect them from abrasion and to help maintain the integrity of the objects. Conservators rely on subjective opinions about fabric properties in choosing materials for their overlay treatments because objective data are not available. Textile properties, such as abrasiveness, of sheer overlay fabrics play a role in the success of conservation treatments over time.

A survey of textile conservators provided data about the use of overlay fabrics including criteria for selection and type of objects being treated. Cross tabulation of the data revealed trends in the use of sheer overlay fabrics.

Eleven fabrics were purchased from retailers. Properties, such as yarn type and woven or knit structure, were described, and eleven different textile performance tests were run. Nylon net was significantly more abrasive than polyester georgette and polyester English net. Three nylon nets were the sheerest fabrics. Other properties of sheer overlay fabrics measured in this research included cover, gloss, weight, thickness, surface roughness, coefficient of friction, elongation, electrostatic cling, and stiffness. Photomicrographs of fabrics and a summary table of specific fabric properties provide textile conservators with valuable information to use when selecting overlay fabrics.

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CHAPTER 1

INTRODUCTION

Fragile fabrics in textile collections are subject to deterioration due to use, improper handling, exhibition, and storage. Textile conservators play an important role for museums and collectors by reducing the rate of this deterioration. Conservators do not try to restore a textile object to a pristine or new-looking condition, but rather seeks to protect the textile from potential harm. They use cleaning techniques, stitching techniques, consolidation techniques, and control of the display and storage environments, among other things, to prolong the life of an object. Modern fabrics as well as historic ones can be damaged by exposure to light, environmental pollutants, and changes in temperature and humidity, which affect the long-term stability of textiles. Conservators work to minimize these types of damage.

One method frequently used on fragile textiles that are fraying, splitting, or shattering is the use of a new sheer fabric sewn directly over the deteriorating fabric(s). The sheerness allows the color and pattern of the original fabric to show through, but keeps the damaged fabric intact. These protective fabrics are called sheer overlays and are used on weakened fabrics to protect them from abrasion and to help maintain the integrity of the textile objects.

Results of a survey done by this author, shown in Appendix A, show that conservators choose overlay fabrics for a variety of reasons including sheerness, fiber content, color, strength, hand, and availability. Conservators rely on subjective opinions about fabric properties in choosing materials for their overlay treatments because objective data are not available. Objective data would allow conservators to choose fabrics for technical reasons. Textile properties such as the abrasiveness of the sheer overlay fabrics play a role in the success of conservation treatments over time. The sheer fabrics themselves may be detrimental and may contribute to an object's deterioration through abrasion rather than protecting the object during exhibition and storage. An evaluation of the abrasiveness of overlay fabrics will help conservators make an informed choice. This research studied the abrasiveness of typical overlay fabrics when abraded against a fiber donor fabric using non-accelerated test methods.

Relationships between the physical and mechanical properties of fabric are complex because of the multiple structural levels within fabrics. Fibers, yarns, and fabrics each have their own "geometrical and mechanical variables which control or influence to varying degrees the fabric behavior" (Pan 1996, p. 312). The objective of this research was to compare the abrasiveness of frequently used sheer overlay fabrics and to identify predictors for abrasiveness to be used when testing equipment is not available. After identifying the most typical overlay fabrics used by conservators today, a variety of fabric properties including fiber content, yarn type, fabric structure, weight, cover, gloss, stiffness, elongation, coefficient of friction, surface roughness, abrasiveness, and electrostatic cling were analyzed. These properties of the overlay fabrics were correlated statistically with the abrasiveness results as measured by digital image analysis of loose fibers on the overlay textiles after fabric-to-fabric abrasion. Statistical analysis of the data from the textile performance analyses provided insight into the interactions of the tested variables with abrasion and with each other. The results of this research will provide textile conservators with valuable information to use when selecting overlay fabrics.

The ability to protect without harming a fragile textile is vital. Simpson (1993) did several studies looking at the ability of backing fabrics to protect without harm. She commented that backing fabrics for conservation "should not introduce any circumstances that may weaken the historic textile" (p. 86). This also should apply to fabrics used as overlays. This research extends the Simpson research to sheer overlay fabrics.

Conservators do not agree on the most appropriate fabrics to use as overlays for projects. Mailand and Alig (1999) recommended nylon net as an appropriate fabric for use as a sheer overlay. Landi (1998) suggested different fabrics for different uses including nylon net, Stabiltex, and silk crepeline. Blum and colleagues chose to use nylon bobbinet rather than Stabiltex or crepeline when conserving the Ormerod bedcover for its sheerness, dyeability, and width (Blum, Reiter, and Whelan 2000).

Many historic and fragile textiles on display in museums and galleries are composed of multiple layers. Some have hung in the same vertical position for many years. Gravity affects these textile systems, and an overlay added to the textile system by conservators adds one more potentially damaging variable to an object. If the components move at different rates, due to gravity or environmental conditions, and if any of the components are abrasive, damage will occur to the adjacent components.

Annis and colleagues studied "fiber transfer, the release and relocation of individual fibers from their original positions within a textile" (Annis, Bresee, and Cooper 1992 p. 293). Because abrasion in an exhibition or storage setting could be a slow but ongoing process, the ability to evaluate abrasion by single fiber transfer is important. This research used the single fiber transfer methodology developed by Annis et al. to evaluate the abrasiveness of sheer overlay fabrics. It also analyzed other mechanical and physical properties to study how fiber, yarn structure, and fabric structure affect single fiber transfer. The other properties also were evaluated for use as potential indicators of a fabric's abrasiveness and for use by conservators when selecting sheer fabrics as overlays.

CHAPTER 2

REVIEW OF LITERATURE

Sheer Fabric Overlays in Conservation and Restoration

Textile conservators traditionally have chosen sheer fabrics such as nylon net, tulle, bridal veil illusion, bobbinet, silk crepeline, and polyester Stabiltex (also known as Tetex) as overlay fabrics to protect and support fragile and damaged fabrics from further deterioration during exhibition and storage (Ordoñez 2001). Many historic costumes, flags, and bed coverings are made of silk fabric. Silk degrades with heat, light, excessive weighting, and age and often is found shattered in nineteenth- and twentieth-century textile objects. "The conservation of highly degraded shattered silk is problematic and as yet there is no entirely satisfactory approach to treatment" (Halvorson 1991 p. 4). Overlay fabrics often are used to protect fragile or damaged textiles made of silk and other fibers. Nineteenth-century dark brown cotton fabrics in quilts and costumes are another example of fabrics where sheer overlays are used. These brown fabrics are frequently seen in a degraded condition due to the dyeing process they underwent in processing.

In a discussion of overlay fabrics, Lodewijks and Leene (1972) commented on the importance of sheerness, noting, "fabrics to be applied should be chosen to correspond with the object. A first requirement is that they should be as transparent as possible" (Lodewijks and Leene 1972 p. 142).

Thomsen (1988) reported that use of silk crepeline continues in conservation "because of its receptivity to dyeing" (p. 33). Silk crepeline has the drawbacks of edges that fray easily and a weave structure that easily distorts while being manipulated. Nancy Kirk (2005) of the historic quilting website, The Kirk Collection, recommended silk crepeline for conservation but had a reservation about using it on frayed or broken fabrics on quilts noting that "it does not prolong the life of the original fabric, but does help keep it in the same plane as the quilt." Another quilt restoration specialist commented in the TEXCONS textile conservation Internet discussion forum that she did not like silk crepeline because it "masks the true colors of the textile…by putting a fine haze over the piece." She went on to say that it does nothing to stop or slow the deterioration of the textile (Syler 2002). Mailand and Alig (1999) recommended the use of nylon net "over and behind a vulnerable hole or edge" to prevent fiber loss or damage in deteriorated textiles (p. 36).

Rice (1972) recommended using synthetic fiber gauze such as nylon or a fine silk netting or crepeline as a protective sandwich for a fragile textile during wet or dry cleaning. In the case of a three-dimensional item such as clothing, he suggests a fine net bag made of nylon or cotton. Lodewijks and Leene (1972) also recommended a sandwich of fine "polythene gauze" when washing a fragile silk flag. He cautioned readers to choose the gauze carefully, as gauze with a small mesh such as polyester or silk crepeline would capture the larger particles of dust and dirt and prevent their removal. A coarse mesh might cause an imprint on the flag after drying. They also cautioned against the use of thick tulle fabrics in conservation because the "texture may become imprinted into the thinner material of the object to be restored…the hardness of the yarn will cause further wear of the restored object when it is handled" (Lodewijks and Leene 1972 p. 142).

Historically conservators chose overlay and support fabrics to closely match the fibers and yarns in the object according to Landi. More recently, synthetic fiber fabrics are gaining favor in the conservation community because of their supposed "greater resistance to environmental factors." She recommends that the ideal would be to match the reaction to environmental changes in the overlay fabric to the reactions of the textiles in the object (Landi 1998 p. 7.2).

Quilts

Sheer overlays of net may be used in quilt conservation, not to provide for short-term use by the current owners, but to maintain the history of the quilt into the centuries ahead (Wasserman 2002). Pampe (2002) suggested that sheer illusion or crepeline should be used to protect damaged areas during quilt restoration. In a 1987 Cooperative Extension bulletin on quilt conservation, Ordoñez (1987) wrote that net or tulle may be sewn over weak or damaged areas for temporary support during wet cleaning. She no longer recommends this practice based on her own research and research done by Simpson on the abrasiveness of backing fabrics.

In 2000, conservators sandwiched the Ormerod Bedcover between nylon net and a cotton support as a part of its conservation in Philadelphia. They stated: "nylon bobbinet was chosen over crepeline or Stabiltex because it was the least visible." They noted a fuzzy sheen on the surface with crepeline and Stabiltex, especially when viewed from the angle at which the piece was to be displayed. Other positive attributes of the nylon net was its availablity in widths wide enough for the bedcover and it could be dyed in-house (Blum, Reiter, and Whelan 2000 p. 26).

In discussing crazy quilt restoration, Cognac (1994) commented: "some restorers of crazy quilts recommend netting. However, netting does not stop silk from flaking. Indeed, the netting can turn into pouch-like receptacles that hold the silk debris" (p. 44) She noted that netting can camouflage and obscure any embroidery on the quilt. In another chapter of her book, however, Cognac wrote that "fine crepeline, tulle, or netting can be applied to the damaged sections of a crazy quilt" (p. 74) She suggested using different shades of net to enhance the fabric underneath and offered suggestions for attaching the netting with the fewest stitches possible. Quilt restorers are recommending the use of the newest nets to their students and clients without the knowledge or research to confirm that the nets are appropriate for the textile (Quilt-Restorers 2001; Wasserman 2002).

A Kansas State University Cooperative Extension booklet found on the web recommended using sheer fabrics to cover frayed or broken fabrics to "prevent further damage but allow the color to show through." The authors suggested using fabrics such as tulle, chiffon, and silk or polyester crepeline (Burke and Ordoñez 1989 p. 5).

Flags

Flag conservation is another area in which conservators frequently use sheer overlays. The Museum of the Confederacy conservation program, in Richmond, Virginia, uses Stabiltex for flag encapsulation. Conservators sew around the perimeter of the flag and its fragments and in areas where material has been lost on the flag, taking special care not to sew through the fabric of the flag (Rawls 2002). Conservation of a pair of British regimental flags was accomplished by "sandwiching them between two layers of nylon net" (Lennard 1995 p. 179). Stitching through the layers of net and not through the flags provided support. Lodewijks and leene also recommended a sandwich made of two layers of silk or polyester crepeline, dyed to match the deteriorated flags (Lodewijks and Leene 1972).

Thomsen (1988) wrote that she started to use plain-woven, multi-filament polyester Stabiltex for flag conservation when it became available. She had previously used silk crepeline but found that "fragility and sensitivity to light were limiting factors." The newer fabric also had drawbacks. Even though the Stabiltex is durable, strong, sheer, and available in a number of colors, the one-meter width is too narrow for many flags, making piecing necessary. The soft plain weave with no apparent sizing resulted in heavy fraying at the cut edges. The fabric's resistance to folding without heat setting makes encasing an edge difficult and leaves a strong colored line.

Pollak and Thomsen (1991) reversed previous treatments on a Civil War era painted flag and then encapsulated the flag in custom-dyed blue Stabiltex. Two widths of fabric were hot-melt seamed to make a piece large enough to cover the flag. They stated that the seam was visible as only a thin line. The fringe for the flag was separately encapsulated in gold-colored Stabiltex.

Conservation of the seven banners of St. Andrew's Church in Grafham, Cambridgeshire, UK, included stabilization "by applying an overlay of adhesive coated silk crepeline, dyed to a sympathetic colour." The conservators chose overlays instead of underlays where the area of loss was not accessible from the back, and it was "too fragile to withstand insertion of patches behind the weak areas from the front." They used silk fabric underlays on the areas of the banner with complete loss of silk in addition to the crepeline overlay (Townsend 1999).

In an article detailing a method for cutting a shape out of an overlay for a thickly embroidered section of an historic military flag, Dancause (2002) discussed the complex set of criteria used to choose a textile for a sheer overlay. The fabric needed to be colored, sheer, and strong and "to complement the disparate elements composing the artifact" (p.1) It also needed to provide support to the weak ground fabric but have openings cut without fraying to allow the embroidered crests to stand above the ground without an overlay. The conservators chose to use Stabiltex and hot-melt cutting was developed to stabilize the edge of a cut without fraying.

Underlays of colored cotton, mimicking the flag's design, were used during restoration a Civil War era flag to minimize the visual disturbance of missing areas of the flag. The conservators then used hot-melt cut overlays of colored Stabiltex to further correct the color differences between underlay and flag (Pollak and Thomsen 1991). Sheer fabrics also can be used as supports for flags such as the Ocean Pond flag of the 6th Florida Battalion in the Civil War. The flag "was hand-sewn to a single layer of polyester Stabiltex fabric for support" (How is a Flag Stabilized 2002). Lodewijks and Leene (1972) recommended a "dummy" flag made of crepeline or other thin material be placed over or under deteriorated flags "to give the impression of the original" but not "distract the observer's attention from the original fragment" (p. 174).

Costume

The textile conservator the Peabody Museum of Archeology and Ethnology reported that she stabilized the ribbons on a Micmac chief's coat by encasing the ribbons at the front panels and along the hemline in a "fine polyester (crepeline-like) fabric" (Holdcraft 1998). Bacchus reported that conservators chose silk crepeline as an overlay on an Egyptian tunic at the Fitzwilliam Museum in Cambridge, UK, because it "was not visually intrusive, but clearly distinguishable from the original object on and off display" (Bacchus 1998 p. 13). Ekstrand (1972) reported on the conservation of a black silk ribbon, which supported the standing brim of a hat, by stitching it to "a strip of selvedge of tulle" (p. 194).

Archeological Textiles

Negnevitsky and Schick (2000) chose to use two different sheer fabrics to conserve a large linen burial cloth in Israel, based on specific features: "Stabiltex and silk crepeline were selected. The former, a pure synthetic, is the stronger of the two—a positive feature; but the latter is the more transparent and less glossy—a positive feature for display and study" (p. 147). As a part of the treatment, the 6000-year-old textile was sandwiched between Stabiltex and silk crepeline.

Household Furnishings

In the *Care and Preservation of Textiles*, Finch and Putnam (1985) stated that using a net or crepeline cover over furnishing fabrics "will not prevent actual deterioration, but it will ensure that any potentially loose threads are kept in place and not rubbed away and lost" (p. 265). She noted that this provided the "least possible chance of the fragile fibers being broken, twisted, or pulled out of shape" (p. 265). She also recommended the use of net coverings over hooks, eyes, and snaps to protect the rest of the object from damage during wet or dry cleaning.

When wall hangings at Ham House, Surrey, UK, were conserved, the staff discovered that the back of most panels had been adhered to a silk tulle net support. The patterns of the net underlay created impressions on the front of the damask in several places. The conservators noted that those panels adhered to net had greater warp face breakdown than those not adhered to net. The breakdown of the damask warp face had been exacerbated by the rigidity of the adhered net backing. During the 1990 treatment, conservators chose to use Stabiltex overlays because of its durability and resistance to photo-degradation and chemical attack. They commented: "Stabiltex is denser in appearance than nylon tulle, but its visual appearance is quite acceptable when used vertically" (Hillyer 1990 p. 187).

Conservators prepared an historically important curtain at Uppark, West Sussex, UK, that had been damaged in a house fire for long-term storage by sandwiching it between "two layers of dyed conservation net." Stitching around the burnt fragments and along the festoon lines held the net in place. They encased the fringe separately in net and rolled the entire package on an acid-free tissue-covered

PVC roller for storage (Marko 1995 p. 114). A tester cloth with a large burn hole from the Uppark state bed, damaged in the same fire, was treated with a piece of dyed nylon net over the damaged area and stitching beyond the margins of the hole into strong areas of the damask (Singer and Wylie 1995).

Dyed net, cut to fit, was the overlay of choice for faded historic silk wall hangings at Arlington Court, Barnstable, Devon, UK. The object of this conservation was to "even out the visual differences between faded and unfaded silk and to protect the silk from the light and damage caused by visitors" (Hutton 1995 p. 168). The conservators concluded that the net improved the visual appearance and perhaps provided a barrier between visitor and silk wall covering. They were not sure that the net would provide any protection from photo deterioration, although they took other measures such as keeping the drapes closed to control light levels. In addition, they stated, "although many of the larger degraded areas were supported, the net did nothing to support the overall weakness of the hangings" (Hutton 1995 p. 170).

A conservator used dyed nylon net to conserve chair seats at Felbrigg Hall, Norwich, Norfolk, UK. She secured the net under the back seat rail of the chair and gently tensioned it to the front. She tucked the net inside and secured it with lines of support stitching. She also used an underlay in this treatment, and the conservator felt that "the weak and damaged area of silk was well supported by the combined patch support treatment and the nylon net covering" (McClean 1995 p. 184).

Daily control of dust in historic houses and museums is essential. Lloyd (1995) suggested that covering the upholstery tool of a typical vacuum cleaner with fine nylon net and vacuuming directly on the upholstery surface was an appropriate way to clean furnishings. Lodewijks and Leene (1972) recommended the use of tulle as a screen over the mouthpiece of a vacuum cleaner prior to vacuuming historic textiles and furnishings. Owen (1995) of the Victoria & Albert Museum recommended that dyed nylon net be sewn over badly degraded textiles in house museums "to protect and tidy" them until full conservation is possible (p. 186).

Objects with Missing Parts

Conservators at the National Park Service Division of Conservation, Harpers Ferry Center, Maryland, used a painted overlay to compensate for lost fabric in the deteriorated border of a cotton quilt owned by Hampton House, London, UK. They first considered an overlay stitched over the border, but decided that the white batting would continue to show through and be visually disturbing. The complex fabric pattern and the quilting design made adding fabric infills difficult. They decided to try a paint medium on the sheer overlay because color mixing and matching would be easy and painting was a good way to deal with a complex design. They considered three sheer fabrics and rejected nylon net because of its open structure and aging problems. Finally, they chose silk crepeline over polyester Stabiltex because it had less sheen and was easier to dye. The conservators first dyed the crepeline dark brown and then brushed the cut edges with a dilute semi-gloss acrylic medium to prevent fraying. Painting proceeded with a Mylar interleaf between the quilt and the overlay. After the paint was dry, they removed the Mylar and stitched the overlay into place along the long edges and through some of the original quilting stitches. The curator of

Hampton House was satisfied with the final appearance of the quilt and agreed to allow only limited exhibition of the quilt in the future (Schmalz 1999).

Effect of Exhibition and Storage Conditions on Textiles

Environmental changes, such as variations in temperature and humidity, occur in exhibition spaces where textile objects are on display. Such changes might be stressful for an object already weakened through age and deterioration. Storage in ideal conditions may not cause stress to an object, but not all objects are stored in ideal or consistent conditions. Handling during examination, photography, conservation, and exhibition all put strain on an object. Movement between environments for these tasks is potentially damaging. "Early restoration or conservation treatments may have caused deterioration, even though most of them were carried out with the best of intentions" (Pye 2001 p. 93).

Stretch Due to Gravitational Forces

Simpson (1991), based on her research on the abrasiveness of backing fabrics in conservation, suggests that a rough support surface is detrimental to a fragile textile on display due to its cutting into the delicate fibers and fabrics. She noted that this is a particular problem with vertical display or storage of a textile that allows gravitational force to exert pull on a historic textile against a backing fabric. Changes in temperature and humidity also cause movement of the two fabrics against each other. Simpson also states that "even general handling of the item such as lifting and repositioning may cause movement of the two fabric surfaces against each other" (p. 179).

In research done at the University of Rhode Island to test padded hangers for storage of historic costumes, McGrath (2003) showed that cotton gingham bodices, cut on the bias and weighted along the bottom, stretched as much as 13 mm while hanging for 14 days. The stretch ranged from 4 mm to 13 mm depending on the area measured of the bodice and size of hanger. None of the test bodices was exempt from stretch. This experiment showed the effect of gravity on a simple garment made of gingham fabric. Most historic garments and textile objects are systems of multiple fabrics and/or yarns. Gravity will affect these textile systems, and it may affect different fabrics and fibers differently. When conservators add an overlay to the textile system, one more element is subject to gravitational pull. If the components move at separate rates, and if any of the components are abrasive, damage could occur to the other components.

Townsend (1999) reported that gravity and environmental conditions in the St. Andrews Church, Grafham, Cambridgeshire, UK, over a period of 100 years caused the upper edge of all the decorative banners to fall into scallops and hang in undulations between the loops that supported them. In a report about the conservation of a Civil War era flag, Pollak and Thomsen (1991) noted that the vertical stitches connecting layers of fabrics were not secured at the bottom of each stitching row "to allow for possible movement of fabrics in the flag as it was displayed" (p. 15).

Dimensional Change Due to Temperature and Humidity

Many textiles, especially those made from cellulosic and protein fibers, expand and contract with changes in humidity. The resulting changes in size and morphology result in movement and friction. “Physical damage can be caused by juxtaposition of materials which expand and contract at different rates and to different extents” when exposed to changes in temperature and humidity as exemplified by paintings on linen canvas on wood stretchers (Pye 2001 p. 90). Changes in relative humidity (RH) affect organic objects by changing the rates of chemical reactions and affecting the physical properties such as size, strength, and stiffness (Erhardt and Mecklenburg 1994). A condition report made prior to conservation of the seven banners belonging to St. Andrew’s Church stated that “the appliquéd fabrics appeared wrinkled in places, suggesting that the foundation linen had shrunk due to the environment of the church” (Townsend 1999).

Berger and Russell’s (1990) research on the responses of canvas paintings to controlled environment changes is relevant here. They found that “every canvas measured… responded to changes in relative humidity and temperature . . . and these responses often changed gradually during testing” (p. 2). The responses of stretched canvases varied greatly. For example, the tension in one canvas (linen, light weave, commercially sized, acrylic primed) rose with a rise in relative humidity while a second canvas (linen, basket weave, commercially glued and primed with oil paint) showed peak tensions during periods of low relative humidity. Individual canvases had a wide range of tension values in response to combinations of relative humidity and temperature, and generalizing about the variations was difficult. This may be due to different sizing treatments, types and styles of stretchers, type of paint, and painting technique. It also might be due to differences in the linen yarns used to weave the canvas and even the sett, weave structure, and finishing of the canvas fabric itself.

Berger and Russell (1990) found that exposure to high relative humidity produced a rise in tension in the canvas and permanently deformed and enlarged the canvas. He noted that when a fabric loses its tension, it also loses its elasticity and its resistance to deformation. "Once stretched out, canvas can never be pushed together again by mechanical means" (p. 4). Cycling environmental changes caused by intermittent exposure to lamps or reflectors in a gallery situation also are important considerations. Erhardt and Mecklenburg (1994) state, "moderate changes in relative humidity produce minimal problems in materials that are free to expand and contract." They go on to say that larger changes cause problems even for those objects free to expand and contract because the rate of moisture diffusion takes time and different materials have variable rates, causing swelling or contraction of one part of an object with potential damage to other parts.

Padfield's (2003) research indicated that "temperature change, typically between ten and twenty degrees, caused more change of stress than a RH change between 15% and 55%" (p.2). This is a serious challenge to the prevailing orthodoxy that conservators can be relatively careless about the temperature but must insist on a steady relative humidity. Furthermore, the reaction of paintings on fabric to small, rapid temperature changes was disproportionately large compared to changes in humidity alone. The effect of the rate of change of environmental variables is a subject that looms large in the field of conservation.

Berger (1981) observed the good condition of a set of gigantic Atlanta Cyclorama dioramas that traveled around the USA in the last century. These pictures were rolled up for transport, between being exhibited hanging from a hoop. Another hoop, loaded with weights, held the bottom under tension. The bottom, therefore, was free to rise and fall with the changing climate. The variable waistline of the diorama allowed the shrinkage in the middle of the canvas to relieve the horizontal stresses.

The affect of moisture on abrasiveness and abrasion resistance is complex. Moisture serves as a lubricant, reducing the friction between a fabric and another surface, potentially slowing the abrasion process. Damp, swollen fibers are also less brittle. Many factors must be considered when observing the interactions between environmental conditions and abrasiveness. For example, fabrics made of fibers that are stronger when wet than dry have better resistance to wet abrasion than to dry abrasion, and conversely, fabrics of fibers that have lower tensile strength when wet than dry may abrade more easily when wet (Collier and Epps 1999). Barring disaster, textiles on display and in storage may not be thoroughly wetted, but changes in relative humidity will affect the abrasiveness and abrasion resistance of any two fabrics in contact with each other.

Airborne Pollutant Damage

Airborne pollutants, which can settle on any unprotected surfaces of textiles and objects, can cause discoloration, mold-growth, and abrasion. Airborne pollutants include sulfur and nitrogen oxides that can react with water to form acids and ozone - an oxidant. Particulate pollutants include dirt, and building and display materials such as concrete dust, wood, wood composites, adhesives, textile fibers, and textile finishes that can all release alkaline particles, organic acids, formaldehyde, or hydrogen sulfide. Dirt particles can penetrate into porous objects, while oily pollution will sit on the surface. Airborne dirt includes gritty particles, tiny bits of skin, carbon particles, oil droplets, bacteria, and mold spores (Pye 2001).

Pollak and Thomsen (1991) report that a Civil-War-era painted silk flag brought to them for conservation had suffered from a 1970 conservation treatment. It was pressure mounted in a painted pine frame and covered with two sheets of Plexiglas with 1/2 inch gap between the two adjacent sheets. The gap allowed airborne pollutants to reach the flag. In 1970 the flag fragments were glued to a silk crepeline backing with a water-soluble adhesive. An overlay of silk crepeline was added, and the entire sandwich was machine-stitched with synthetic mono-filament thread over the entire surface of the flag. The adhesive was washed out, and the flag ironed "to set the stitches and further flatten the flag." By 1990, the conservators noted that the "previous treatment was causing continued stress and damage to the flag." The silk crepeline overlay had been dyed blue to match the flag, but in 1990 it was a "dull grimy blue-grey color that greatly obscured the design" (pps. 10, 12). The crepeline had become brittle and no longer provided support or protection for the flag.

Pressure-Mount Framing

The Museum of the Confederacy stores its flag collection flat in a new storage facility. Flags destined for exhibition are laid on an unbleached cotton panel over acid-free board padded with polyester batting. If a flag has been encapsulated in

Stabiltex, it is sewn to the backing fabric through the sheer fabric. For exhibitions the conservators cover the flags with ultraviolet-blocking Plexiglas and add a custom-made aluminum pressure mount frame to apply light pressure to the entire sandwich (Rawls 2002). Pressure mounts are designed to prevent movement of the textile-mount sandwich layers. The pressure might be strong enough to cause the strong synthetic yarns of the overlay to cut into the silk flag. "Sometimes a small degree of friction is helpful in holding the two textile items together so that they do not slide apart easily" during display (Simpson 1991 p. 179). The long-term effects of pressure mount framing have not been studied.

Studies of Abrasiveness of Textiles Used in Conservation

Crockmeter Abrasion Tests

Simpson (1991) studied the abrasiveness of support fabrics used in textile conservation by rubbing two fabrics together with a crockmeter. Crockmeters generally are used for testing colorfastness to crocking in dyed fabrics. Simpson chose to use it because no standard test method existed for measuring fabric-to-fabric abrasion at low levels of force. She also wanted to develop a "simple, inexpensive test method that a conservator might use in a conservation laboratory" (p. 179). Her research followed American Textile Chemists and Colorists (AATCC) Test Method 8 using a linear crockmeter. Simpson placed brightly colored, napped, 100% cotton flannel on the upper peg and the support fabrics on the base. After ten rubbing cycles, she counted the numbers of fibers loosened from the flannel during abrasion by the four unbleached, 100% cotton support fabrics. She found statistically significant differences in abrasiveness between the four fabrics. Fabric construction, including weave structure and weight, had a significant effect on the amount of fiber removed from the flannel fabric. Of the tested fabrics, only the sateen weave showed a difference between the face and back of the fabric. Simpson's methodology did not replicate actual conditions of storage or display, but it did provide a "procedure for measuring fiber loss due to abrasive action of fabric surfaces" (p.91). Simpson (1991) selected the simple method of counting the number of loosened fibers and fiber particles transferred from one fabric to the other during abrasion using a linen tester for magnification to evaluate the fabric-to-fabric abrasion.

Simpson (1993) continued her investigations of fabric-to-fabric abrasion and fiber transfer with eleven new fabrics. She again used a 100% cotton napped flannel as the "fiber donor fabric" and the crockmeter to provide the low-force abrasive action. Statistical analysis showed that the eleven fabrics could be grouped by their abrasiveness with tulle being the most abrasive and the group consisting of muslin, velveteen, and two weights of laminate as the least abrasive. Inverse relationships for weight and thickness compared to abrasiveness resulted for tulle and velveteen, but for simple woven fabrics with similar abrasiveness values for both face and back, the heavier and thicker the fabric became, the more abrasive it was.

Simpson (1993) concluded that the reasons the tulle was the most abrasive were its low yarn count, open structure, and mono-filament yarn. Fabrics with modified basket weave, satin weave, and knit (jersey and rib) structures showed a moderate amount of abrasiveness and were not statistically significantly different from each other. The plain weave and the pile weave fabrics were the least abrasive. Her results allow textile conservators to select backing fabrics with low surface abrasiveness for mounting fragile textile artifacts.

Abrasion Resistance Testing

In 1990, Annis and Bresee wrote that "the results obtained with accelerated abrasion tests frequently do not correlate well with actual wear" (p. 264). They developed a machine that controlled the speed, direction, and force of fabric-to-fabric abrasion to evaluate the abrasion resistance of textile materials. Annis and Bresee called it non-accelerated abrasion although this is a misnomer because all abrasion in laboratory conditions is conducted at a rate higher than that in actual use. However, the term serves to describe the controlled rate of abrasion to a non-destructive endpoint used by the Annis and Bresee research. Their machine is capable of abrading slowly, with small fabric-to-fabric abrasion forces and end-points prior to complete destruction of yarn or fabric. They chose to use "single fiber transfer" as the evaluation method similar to that of Simpson's research. This method of analysis is "particularly appropriate when relatively minor abrasion damage is of interest" (Annis and Bresee 1990 p. 264). Specific mechanisms of abrasion at the molecular, fiber, yarn, and fabric stages can be analyzed using low levels of abrasive force (Annis 1990). The analysis of fiber transfer can be used to detect abrasion damage as limited as the loss of a single fiber fragment. They define fiber fragment as a short piece of fiber broken horizontally across the fiber, not as longitudinal fibrillation. This research also uses this definition.

Forensic science research has identified three basic mechanisms of fiber transfer: shedding of loose fibers residing on a textile's surface, disentanglement and removal of whole (unbroken) fibers partially embedded in a textile's interior, and fracture of whole fibers followed by the release of fiber fragments (Pounds and Smalldon 1975). Fiber transfer plays a part in most textile wear mechanisms. All of the research by both Simpson and Annis used single fiber transfer analysis to observe and measure all three mechanisms when they happen in a controlled setting. The machine developed by Annis and Bresee (1990) discriminated between fabrics that were similar in structural characteristics but differed in fiber length, breaking strength, and yarn weave structure. The fiber transfer in the Annis and Bresee research occurred as a result of fiber fracture or a combination of fracture with fiber slippage due to the shortness of most of the transferred fibers.

A subsequent study in 1992 by Annis, Bresee, and Cooper evaluated the influence of various structural features of fabrics and showed that fabric weave, fiber denier, and fiber length affected fiber transfer. Their research into fuzz formation and linting in 1998 showed that the frictional energy of fabric-to-fabric movement and textile structure are important factors to evaluate in understanding textile abrasion (Annis, Hsi, Bresee, and Davis 1998). Fuzz forms when fibers are fractured and pulled from yarns producing lint or fuzz on the fabric surface. They measured fuzz as the height of the entangled fibers above the fabric surface. Further research in this area resulted in an understanding that the yarn interlacement pattern influences the amount of frictional energy transferred from one fabric to the other and accounted for the differences in fuzz formation (Annis et al. 2001). Backer and Tanenhouse (1951) observed the differences in abrasion performance "when the direction of rubbing is altered with respect to warp and filling coordinates" (p 648). Annis and colleauges also showed that more and longer fuzz was produced by orbital abrasion than by linear abrasion (Annis, Davis, Bresee, and Hsi 2001). During fabric-to-fabric abrasion, distinguishing the fibers from each fabric is essential. Annis and Bresee accomplished this in their research by the choice of fabrics of very different colors or by dyeing one of the fabrics with a fluorescent dye (Annis and Bresee 1990).

Analysis of Single Fiber Transfer

Annis and Bresee (1990) defined single fiber transfer as "the release and relocation of individual fibers from their original positions within a textile material" (p. 264). In their earliest work, they suggested several different methods of analyzing abrasion via single fiber transfer. Researchers could develop standard photographs for comparison purposes. Alternatively, they could employ simple counting systems, like Simpson, to count the number of transferred fibers. Counting systems, combined with removing and measuring fibers longer than 2 mm, also were tried and achieved results that included the number of fibers, mean length of fibers, and a length distribution (Annis, Bresee, and Cooper 1992). Ultimately, Annis chose to use microscopic video imaging to compare fabric surface changes qualitatively (Annis, Bresee, and Warnock 1991). Digital photo-micrographs allowed for various digital measurements and comparisons of the individual fibers (Annis 1990). Simpson (1991) suggested that weighing on a very accurate scale could evaluate the amount of fiber transferred. In later research, Hsi, Annis, and Bresee (1998) reported on improved image analysis for analyzing the fuzz left on fabrics after non-accelerated abrasion. This method of analysis required specialized hardware, software, and trained personnel.

Research on Physical and Mechanical Properties of Fabric

Physical Properties of Fabrics

Many properties of fabrics contribute to their suitability as overlays. These include cover, luster, gloss, construction, finish, abrasiveness, friction, stiffness, roughness, elongation, and electrostatic cling. The following discussion explores these properties.

Cover

The amount of cover provided by a sheer overlay is critical to the success of a treatment. The definition of cover is "the ratio of fabric surface occupied by yarn to the total fabric surface" (Kaswell 1963 p. 450). Cover is important when considering light, moisture, or water vapor penetration. Cover can be considered a measure of transparency because transparency implies the passage of light through a textile. Transparency and sheerness often are linked in the discussion of fabrics. The term sheer is defined in *Fairchild's Dictionary of Textiles* as "transparent or lightweight fabric such as sheer chiffon, crepe, georgette or voile of various constructions" (Tortora and Merkel 1996). Based on fiber content, a textile can be transparent without being sheer, such as a fiberglass curtain. Conservators use sheer overlays for their transparency and associate transparency with lightness of weight and hand. In textile conservation, light permeability of a sheer overlay affects the ability to see the color and/or pattern of the underlying fabric through the overlay. Discussion of gloss, weight, and hand are considered elsewhere in this paper.

Grosberg states that the "shape taken up by the yarn in the warp or weft cross section of the cloth" may be important in assessing the relative resistance of cloths to the passage of air or light" (Grosberg 1969 p. 323). Fabric made of the same fiber, but differing in fabric count, ratio of warp and weft fabric count, ratio of yarn spacing, average of yarn spacing, and/or weave structure may still be "compared for one simple property that is the proportion of the total area of the cloth that is covered by the yarn" (Grosberg 1969 p. 334). Two different fabrics may be considered similar if they "possess the same fractional covering power" (Grosberg 1969 p. 334). For this research, cover is considered a measure of transparency and is called sheerness because of the convention of conservators calling the fabrics they use sheer overlays.

Reflectance, Including Luster and Gloss

Visual characteristics, such as luster or gloss, affect how a sheer fabric looks when placed over a fragile textile. Luster is defined as the "amount of light reflected from the surface of a fiber, yarn or fabric," while gloss is defined as the "luster or brightness of a fabric ... in a specific direction" (Tortora and Merkel 1996 pp. 336-7). A lustrous or glossy fabric overlay might detract from the matte finish of an historic object. The addition of titanium dioxide (TiO_2) to the polymer melt of manufactured fibers in various amounts affects the intensity of fiber luster, sometimes called the brightness of the fiber. The type of fiber or filament and the amount of spin of a yarn affects luster. Filaments are smooth, and this gives them "more luster than spun yarns, but the luster varies with the amount of twist in the yarn. Maximum luster is obtained by the use of bright filaments with little or no twist" (Kadolph and Langford 1998 p. 220). Luster also may affect the abrasiveness of the overlay fabric, because "variations in the TiO_2 content also affect the geometry of the fiber surface, namely, bright polyester fibers have a smooth surface, whereas dull fibers have a rough surface" (Schick 1977 p. 49).

Industry uses a measurement of gloss to "compare and match different components and to develop new effects for textiles" (Breugnot 2004). The overall ability of an object to scatter light defines its visual appearance, while the specific color and the gloss of an object combine to create its visual aspect. Measurement of those two important parameters is crucial to control the quality of the visual characteristics of an object. Often, especially for textiles and garments, the object to be analyzed is non-planar and is a complex three-dimensional surface (KatoTech 2004).

Gloss measurement takes both scattered light and reflected light into account. Because of this, the measurement correlates to human visual observation. A gloss meter evaluates gloss, color-codes it, and then using image processing, creates a mean value for gloss. Gloss measurements are appropriate for textiles because "light scattered by a rough surface is composed of diffused and specular components. The gloss degree of a surface is the proportion of specular reflection compared to the diffuse reflection at the surface whereas the color information is fully contained in the purely diffused light" (Breugnot 2004). Currently, no gloss standards exist for specific fibers or textiles.

Luster can also be defined as the directional variation of reflectance. This means that a glossy or lustrous fabric has the capacity to reflect more light in some directions than in others. Several companies have developed gloss meters that measure luster. In research investigating the effects of weave structure, fiber content, and yarn twist on luster, Kim and Shin (2004) concluded that as yarn twist in multi-filament yarns increases the luster unit size diminishes, which results in a macro-level gloss decrease.

Knitted Fabric Structures

Conservators use warp knitted fabrics as sheer overlays (see Appendix A). Warp knitted structures have "unique properties of form-fitting and elastic recovery based on the ability of knitted loops to change shape when subjected to tension" (Spencer 1989 p. 248). Dimensional changes also can occur during use, and problems of shrinkage, stretch, and shape or size distortion affect consumer satisfaction with the fabric. One of the basic laws governing the behavior of knitted structures (as defined by the Hosiery and Allied Trades Research Association in the UK) is that "loop shape determines the dimensions of the fabric and this shape depends upon the yarn used and the treatment which the fabric has received." Loop lengths within each course affect fabric properties such as weight (Spencer 1989 p. 249).

Fabrics knit from synthetic thermoplastic yarns such as nylon and polyester can be heat set to a shape or dimensions. Hydrophilic fibers, such as cotton and silk, often show dimensional change after knitting, and this can cause major problems for the end user. Spencer (1989) wrote "in theory, knitted loops move towards a three-dimensional configuration of minimum energy as the strains caused during production are allowed to be dissipated so that…a knitted fabric will reach a stable state of equilibrium with its surroundings" (p. 255). Environmental conditions such as temperature and relative humidity will affect this state of equilibrium as will the mechanical properties of the fiber, yarn, and knit structure.

The structure of knitted non-knotted nets is achieved through manipulation of the standard knitting process. "Symmetrical nets are produced when two identically-threaded guide bars overlap in balanced lapping movements in opposition" (Spencer 1989 p. 297). A hexagonal mesh, marketed as tulle by the industry, is produced by an open lap followed by a closed lap that causes the lapping to alternate between two adjacent wales and forms underlaps and inclined overlaps that close the top and bottom of the staggered mesh holes (Spencer 1989).

Tricot fabrics are the lighter end of warp knits—usually less than 4 ounces per square yard or 140 grams per square meter for the apparel and furnishing categories (Thomas 1976). The machines that produce tricot fabric use spring-beard needles. Raschel machines use latch needles. Many raschel machines make laces, plain nets, and elastic nets (Thomas 1976). In addition, according to Spencer (1989) the raschel machine is "more suitable for utilizing synthetic filament yarn than traditional lace machinery" (p. 311). In 1976, when Thomas was writing, he noted, "the boundaries between raschel and tricot fabrics are becoming ever more indistinct" (p. 41). The intervening years have almost certainly accelerated this process. Even so, differences in the physical and mechanical properties of raschel and tricot knit sheer fabrics may affect the abrasiveness of those fabrics and their effectiveness as overlays in conservation.

Fabric Finishes

Fabric finishes also must be considered when conservators choose fabrics for sheer overlays. The behavior of knitted structures depends upon the yarn used and the treatment the fabric has received during production, according to Thomas (1976). This is also true of woven fabrics. These treatments may include fabric finishes to change the appearance or performance of the textile and apply to wovens as well as knits. Some finishes are temporary, applied to facilitate production and construction of the final product. Others are applied to enhance the hand or appearance until the consumer makes the purchase and then may be removed with the first cleaning. Manufacturers call these counter finishes (Schindler 2004). Chemical modification or thermosetting makes other finishes permanent. Finishes that are expected to last the lifetime of a garment are called durable. Collier and Tortora (2001) noted that information about these appearance-enhancing finishes is not usually included on a product label. Finishes applied to affect fabric performance are more likely to be chemically applied than those that affect appearance (Schindler 2004).

Finishes may soften the hand of a fabric or stiffen it. Manufacturers use finishes called hand builders to provide stiffness and added fullness to a fabric. These work because they attach to the fabric surface and accumulate in the spaces between yarns. Individual fibers and yarns are bound together by the finish to create stiffness.

Such finishes are likely to affect properties other than stiffness such as stretch, friction, and surface roughness of a fabric (Schindler 2004). Many of the finishes affect more than one property of a fabric. For example, methacrylates are primarily hand builders, but they also can improve abrasion resistance, adhesion, elasticity, flexibility, and water or solvent resistance depending on copolymerization with other acrylic and vinyl monomers (Schindler 2004).

Conservators need to know which finishes have been used on the fabrics they use for overlays especially because chemical finishes can deteriorate over time and cause changes in the textile. For example, formaldehyde-containing thermosetting polymers tend to "reduce abrasion resistance, yellow after exposure to heat and release formaldehyde" (Schindler 2004 p. 84). Schindler noted other possible draw-backs to hand-building finishes such as "increased soiling and staining of finished fabrics, and increased fabric flammability" (Schindler 2004 p. 92). Unfortunately, retail labels and fabric retailers seldom have information about finishes, and manufacturers do not reveal their formulations of fabric finishes.

Mechanical Properties of Fabrics

Abrasion Resistance and Abrasiveness

The purpose of conserving fragile and historic textile objects is to slow deterioration of the object. Placing two textiles in close proximity, without complete knowledge of the overlay textile's characteristics, may actually contribute to the deterioration through abrasion. Collier and Epps (1999) defined abrasion as "the mechanical deterioration of fabric components by rubbing against another surface" (p. 128). Booth (1969) defined abrasion as "a series of repeated applications of stress" (p. 296) adding that fibers held firmly by tension, pressure, or high fabric count will suffer more stress than those held only lightly. Warfield et al. (1977) agreed with Steigler et al. (1956) that "frictional abrasion has been found to be one of the causes of appearance degradation during use as well as a contributory cause of fabric failure in specific end uses" (Warfield, Elias, and Galbraith 1977 p. 332). Simpson (1993) stated that conservators should avoid placing "rough surfaces adjacent to the historic textile item" because the "rough surfaces of backing fabrics may abrade delicate fibers in the historic textile" (p. 86). "Abrasion...affects the appearance of the fabric" (Collier and Epps 1999 p. 128). Simpson's research made conservators aware of the abrasiveness of backing fabrics, but conservators also need to understand the abrasiveness of sheer overlay fabrics (Simpson 1991, 1993).

Fabric-to-fabric abrasion occurs whenever fabrics are in use. The wearing of clothing provides the most obvious example, but any multi-layer textile in a museum or storage situation can experience fabric-to-fabric movement due to physical handling, gravitational pull, and temperature and humidity changes. "Although these types of fabric-to-fabric rubbing usually do not involve a significant amount of force individually, eventually fabric abrasion will become noticeable when they occur repeatedly, particularly when other types of abrasion occur simultaneously" (Collier and Epps 1999 p. 130). Abrasion also can occur when a textile is in contact with another surface such as a wall, table, or piece of furniture. Individual fabric components may rub against each other causing the yarns or fibers within a fabric to abrade. This is especially important where bent or flexed edges such as folds or creases are rubbed against other surfaces.

Another consideration when evaluating potential abrasiveness is that "particles of dust, sand and other foreign substances held within the fabric can abrade yarns and fibers" (Collier and Epps 1999 p. 131). This is called third-party abrasion. In historic textiles, such as flags, third-party abradants such as environmental pollutants and salt from sea air and water can be very detrimental to the stability of the fabric structure. Past treatment of a textile with soluble salts, such as the iron or tin salts used in the weighting of silk, can introduce a third-party abradant and also cause yarn and fiber deterioration. "In actual use many different abradant forces also act on a fabric at one time, while most laboratory tests simulate only one type of abrasion" (Collier and Epps 1999 p. 138).

Most research on textile abrasion has investigated abrasion resistance, not abrasiveness. Saville (1999) commented that test results regarding the factors that affected abrasion resistance in fabrics are contradictory largely because the tests were carried out using "widely different conditions and in particular using different modes of abrasion" (pp. 195-6). However, these abrasion resistance tests provide insight into the reactions of fibers, yarns, and fabric to abrasion.

After one of the standard abrasion tests, accelerotor abrasion, Warfield and Stone observed that changes included fiber debris, voids, displacement of yarns, and pills for both polyester and cotton fabrics (Warfield and Stone 1979). Specific characteristics of the fiber and yarn play a more important role than just fiber type. Filament yarns are more abrasion resistant than staple yarns because removing elements from filament yarns is difficult. High-twist yarns are more abrasion resistant than low-twist yarns, again because of the relative ease of removing fiber elements from the low-twist yarns (Saville 1999). Low-twist yarns also have the ability to distort or flatten under abrasive pressure, and this allows them to be more abrasion resistant. This ability to distort may cause them to be less abrasive because they can conform to the shape of the other fabric. Nylon is highly abrasion resistant due to its high elongation and elastic recovery; polyester also has good abrasion resistance for these same reasons (Saville 1999).

Fabric structure also plays an important role in abrasion resistance (Saville 1999). Warfield and Stone (1979) pointed out the importance of fabric geometry "in the translation of inherent fiber properties" to the final fabric (p. 251). Woven structures with floats of relative mobility absorb the stress of abrasion better than those without such mobility (Saville 1999). Up to a point, a fabric with a higher fabric count is more abrasion resistant than a lower one, but then, as yarns become too packed to move within the fabric structure, resistance goes down. Warfield et al. (1977) found that tighter, more compact weave structures held fiber ends in the fabric better and inhibited fiber release, breakage, and pill formation.

Becker and Tanenhouse suggested that a firm binding of the fibers through either increased yarn twist or tighter weaves minimizes fiber release. They demonstrated this in wear testing: as twist of either warp or filling yarns increased, the abrasion resistance increased (Backer and Tanenhaus 1951). Warfield et al. (1977) also showed that fabrics with increasing amounts of yarn crimp had more abrasion damage than those with lower crimp. Increases in yarn crimp were associated with increases in filling thread count. Despite numerous tests on a variety of fabrics, the researchers were unable to designate any one fabric as the "best performer in both appearance and performance categories" (pp. 333-40). They noted that neither microscopic observation nor any single physical test was able to adequately evaluate the effect of frictional abrasion on the fabrics tested.

Backer and Tanenhouse (1951) also studied the relationship between the structural geometry of textiles and abrasion resistance. They concluded that better abrasion resistance could be achieved by increasing the geometric area of contact between the fabric and its abradant. An increased number of warp crowns per square inch reduced the normal load per warp crown and increased the abrasion resistance. Normal load is the weight of an object before any force is applied. Increased warp textures (at constant picks per inch) and increased filling texture "resulted in increased fabric cohesion and greater fabric durability" (pp. 636-40). Reducing the flexibility of the fabric by jamming in additional yarns decreased the fabric's durability. They observed that spun yarns in a fabric without a finish had radically altered yarn structure, post abrasion, due to surface fuzz of ruptured fibers. Increasing fabric thickness and larger yarn diameter increased abrasion resistance, although the relationship between thickness and yarn diameter is complex.

Temperature and humidity changes affect the size and shape of textiles, but they also may change the yarn friction and therefore the abrasiveness. Schick noted that the friction of cotton and rayon yarns increased with increasing moisture regain. He suggested that the increase in friction is due to "an increase in area of contact…by the swollen rayon yarn" (Schick 1977 pp. 26, 30, 31).

The inherent properties of individual fibers, the arrangements of fibers in yarns, the arrangement of yarns in fabrics, and finishing procedures used during production all affect fabric abrasion resistance. Most of the abrasion research has focused on woven fabrics; additional research is needed on the abrasion resistance and abrasiveness of knitted fabrics.

Abrasion studies have a large number of material variables to control. At the beginning of her abrasion research, Annis et al. noted that a large number of experimental variables influence the abrasion process, including abrasive force, speed, direction, duration, and numerous human factors (Annis, Bresee, and Warnock 1991). Most standard abrasion resistance tests use accelerated abrasion to an endpoint of a hole or break in fabric or yarn. A large number of tests exist to test abrasion resistance using flat plane, flex, or edge abrasion. Different abradants are used, but none of the standard tests utilize fabric-to-fabric abrasion. Annis has applied for standard test status with a new machine that does fabric-to-fabric abrasion at standard tension, low pressure, variable speeds, and variable directions. This research used Annis's test because it more closely resembled the low levels of abrasion that are seen in conditions of display and storage by collectors and museums than any other evaluation method. The ability to control the speed, pressure, and direction of abrasion were important factors in the test choice (Annis and Bresee 1990). "In planning a trial, a balance has to be struck between what should be done and what can be done" (Saville 1999 p. 206).

Annis and Bresee (1990) defined single fiber transfer as "the release and relocation of individual fibers from their original positions within a textile material" (p.264) In their earliest work, they suggested several different methods of analyzing abrasion via single fiber transfer. Digital image analysis of single fiber transfer is a relatively new technique in fiber analysis, and additional research and refinement is needed to validate it as a method for textile research. The Image-Pro software used for this research is frequently used for analysis in biological and engineering applications, but no research was found that used it for textile fiber analysis (Cybernetics 2005).

Friction

Fabric-to-fabric friction is one of the factors creating abrasion between a sheer overlay fabric and an historic fabric. Ordinarily, researchers measure friction as "the force that resists the movement of an object." Static friction is the force needed to initiate movement; dynamic friction is the force required to keep the object in motion. The phenomenon of friction is governed by a set of laws that "hold fairly well for hard materials, but not for textile materials particularly at low values of normal force" (Saville 1999 pp. 110-11).

During friction testing, Qiu et al. reported that the resulting coefficient of friction values are strongly dependent on test conditions (Qiu, Wang, and Mi 1999). "Since a change in the angle of contact causes a proportional change in area of contact…friction is proportional to the area of contact" (Schick 1977 p. 24). Therefore, if the area of contact in the testing conditions is different from the area of contact in actual conditions, results of measuring of the coefficient of friction may not be applicable to actual conditions.

Many studies have focused on frictional properties of yarn for spinning and weaving operations. Fabric friction is subject to the same rules as yarn friction according to Saville (1999). The angle of contact with the surface and the tension at either side of the contact affects yarn friction. Increasing the angle of contact increases the frictional force due to "an increase in the normal force rather than to the increased area of contact." The frictional force can be kept constant for increasing areas of contact by keeping the angle of contact constant through increasing the radius of the contact surface (Saville 1999 pp. 111-12). These rules of contact may be applicable for the conservation of textiles, especially for those being rolled for storage.

The three "basic factors which determine the frictioanal resistance to mechanical deformation" in textiles are: 1) the ratio of the relative yarn or fiber movement to the fabric deformation as determined by yarn and fiber geometry; 2) the force between yarns and fibers at intersections, which is largely determined by the state of unreleased manufacturing stress in the fabric; 3) the coefficient of friction between yarns and fibers, which is dependent on the fiber type and surface characteristics as well as the presence of 'softening' agents or other lubricants or finishes (Schick 1977 p. 572). Olofsson and Gralen (1950) found that small changes in the fiber surface such as the height and shape of scales on wool yarns produced a large change in the coefficient of friction in fiber-to-fiber friction. Measurements of the coefficient of friction are specific for the two materials in contact with each other, so measuring the friction of each fabric against a standard surface does not necessarily correspond to the friction a fabric will exhibit against another textile surface. This is important to consider when comparing results from two or more studies.

Ajayi (1992) studied the effects of fabric structure on frictional properties in fabric-to-fabric friction. His research showed that the "knuckles" or crowns formed by the crossover of yarns in the two rubbed fabrics became engaged and thus restricted relative motion. He summarized by saying that "the frictional properties of woven fabrics may be interpreted in relation to surface smoothness and texture from the geometric consideration of their component yarns." Ajayi showed that the "frictional resistance to motion increased as the relative area of contact (fabric balance) between the fabrics increased." He also found a similar relationship between frictional resistance, and yarn sett. He concluded, "the frictional resistance of plain weave fabrics is sensitive to small changes in yarn geometry produced by altering yarn crimp, thread spacing, crown height, and fabric balance" (p. 91).

Fabric Hand, Including Stiffness and Surface Roughness

Fabric hand, surface roughness, drape, and stiffness may all play roles in the damage done by fabric-to-fabric abrasion. The evaluation of the sensory properties of hand and drape in a textile is challenging. Subjective testing is dependent on the skill of the evaluators. To effectively evaluate hand and drape, each property must be broken down into its component tactile characteristics such as stiffness, roughness, fuzziness, springiness, and mechanical characteristics such as force to compress, tensile strength, tensile stretch, etc. (Collier and Epps 1999). Quantitative test methods are available for objective evaluation of a few of the tactile characteristics.

A cantilever bending test measures flexural rigidity, which is a measure of the relationship of stiffness to fabric weight (Pierce 1930). Kadolph's (1998) definition of fabric stiffness is "a measure of a fabric's resistance to bending or flexing" (p. 213). In physical terms, more force is required to bend a stiff fabric than a limp one.

Kawabata suggested that quantifying the hand of a fabric required the evaluation of six mechanical and physical properties. These included: tensile properties, bending properties, surface properties, shearing properties, compressional properties, weight and thickness (Kawabata 1980). In 1974, Kawabata et al. developed a series of instruments to quantify the subjective judgment of fabric hand. This is the Kawabata Evaluation System (KES). It combined tests for tensile strength and shearing, pure bending, compression, and surface roughness. It also can test the coefficient of friction on fabric surfaces. Small differences in hand that are difficult even for textile professionals to detect can be quantified by the KES (KatoTech 2004).

Development of the KES system allowed researchers to "relate objective measurement of the important properties in fabric hand to subjective evaluation" (Collier and Epps 1999 p. 269). The instrument was developed for use on fabrics of different construction, weights, weaves, and composition (Sabia and Pagliughi 1987). Chen (1992) noted "a particular need to quantify the relationship between different knit constructions and hand properties," (p. 200) and the KES is ideal for doing that research. Today, the KES is used primarily in the development of new fabrics and the evaluation of fabric finishes (Collier and Epps 1999).

Surface roughness may have an effect on several other textile properties. For example, in research on friction in yarn spinning, Shick (1977) found that "an increase in surface roughness resulted in an increase in charge generation and is more pronounced when the yarn passes a rough guide surface than when passing a smooth one" (p. 52). In addition, Harlock (1989) stated that the mechanical property of surface roughness in fabric relates to the quality and mechanical performance characteristics of abrasion and pilling resistance, but not to abrasiveness.

Elongation

Temperature and humidity changes can cause subtle changes in fabric dimensions, including length. Gravity exerts a steady influence on textiles hung vertically. These and other forces on a fabric create strain, which is the change in length of a stretched fabric divided by the original length; this also is called elongation and stretch. Stress is the force causing this strain. Growth is defined as the permanent increase in length of a fabric after application of a load of a fabric. Elongation, growth, and growth recovery can act as indicators of the stability of a fabric (Collier and Epps, 1999; Tortora and Merkel 1996).

The cross-sectional shape of a yarn changes considerably during fabric elongation. Changes in yarn cross-sectional shape are not as important in knitted fabrics because of three basic factors: the wrap-around nature of contacting yarns in interlocking knitted loops, generally lower yarn-packing densities in knitted fabrics compared with woven fabrics, and the much reduced significance of yarn extension in the deformation of knitted fabrics (De Jong and Postle 1977).

Textiles stretched to less than breaking point do not immediately recover to their original dimensions. The elastic recovery is dependent on the force used, the length of time the force was applied, and the time allowed for recovery (Saville 1999). Textiles in storage and display conditions seldom encounter breaking force stresses, but the subtle long-term changes caused by gravity and humidity may affect elongation and elastic recovery. This, in turn, may affect the effectiveness of an overlay.

Electrostatic Cling

Electrostatic cling caused by electrostatic charge generation affects the performance of sheer fabrics during treatment, and on display, or in storage. A salesclerk in the Fabric Place retail fabric store in Warwick, Rhode Island, commented about synthetic nettings sold there: "this time of year the nylon nets are so full of static, they cling to my hands, my clothes, my hair, and they pick up all the fuzz and dust in the store" (Nancy Clark, personal interview, 9 Feb , 2004).

Electrostatic charge can attract and hold particles such as dust particles and chemical pollutants onto the surface of a textile. These in turn can become third-party abradants when one textile moves against another textile (Pye 2001; Collier and Epps 1999). Kadolph (1998) defined electrostatic propensity as "a measure of the capacity of a non-conducting material to acquire and hold an electrical charge through friction or other means." She defined electrostatic cling as "the propensity of one material to adhere to another because of an electrical charge on one or both surfaces" (pp. 218-19). Electrostatic conductivity is the propensity of a fiber to carry or transfer electrical charges. Fabrics with low conductivity build up electrical charges. Poor conductivity is related to low moisture regain, and synthetic fibers tend to have lower moisture regain than natural fibers and thus lower conductivity and more problems with electrostatic charges (Collier and Tortora 2001). Finishes may be applied to fabrics to improve surface moisture retention and raise conductivity. These finishes help to reduce the problems caused by electrostatic cling, but the stability of the chemical composition of the finish over long term storage or display is a concern.

CHAPTER 3

MATERIALS AND METHODS

Survey

Conservators responded to an internet-based survey on the use of sheer fabrics as overlays in textile conservation, conducted by this researcher, in the spring of 2003. University of Rhode Island Internal Review Board (IRB)-approved e-mails were sent to 378 self-reported textile conservators or restorers around the world. See appendix A for details and results of the survey. Of the e-mails sent out, 263 surveys were deliverable at current e-mail addresses; 43 responded and completed the web-based survey for a response rate of 16%. No follow-up procedures were used to increase the response rate. Results were compiled automatically into a data-base directly from the web survey, so anonymity was preserved.

The survey enquired about the types of sheer fabrics used as overlays in conservation practices and about the types of objects overlays are used on. Respondents used all six fabrics listed in the survey with silk crepeline being the most popular overlay. They used overlays on many different objects, but cited quilts, costume, and flags most often. Conservators and restorers identified sheerness, fiber content, and color as the three most important criteria when choosing fabrics for overlays. Three questions asked about special techniques used with overlays such as adhesive treatments, dyeing of overlay fabric, or painting on the overlay. Two questions investigated changes over time through enquiry about overlay use and fabric choice ten years ago. Demographic questions including educational background, geographic location of practice, and type of conservation/restoration practice were asked. Cross-tabulations on these data revealed trends. Descriptive statistics and the results of the cross-tabulations can be found in Appendix A.

Fabric

Eleven fabrics were chosen for inclusion in this research. Results of the survey done by this researcher indicated that conservators used a variety of fabrics as sheer overlays. The six fabrics listed in the survey (silk crepeline, Stabiltex, bobbinet, tulle, nylon net, georgette) were selected for study. The survey did not specify the fiber content of tulle or bobbinet. Tulle was found in the marketplace in cotton, silk, and nylon, so all three were included. Fabric retailers labeled bobbinet as English net, and it was available in both nylon and polyester, so both of these were purchased. Nylon illusion, one of the fabrics listed under "other" in the survey, was added to the list. One of the retail fabric stores carried a net labeled as polyester net, with a different knit structure than the other fabrics, so it also was selected. In total, eleven fabrics were tested. See Figures 1 to 11 for digitally scanned images of the fabrics with warp direction laying vertically. Fabrics were purchased from a local retail fabric store, a fabric wholesaler, two mail order fabric retailers, and from a conservation supply house. See Table 1. The cost of fabrics ranged from $70.00 per yard for silk tulle to $.69 per yard for nylon net. New sheer fabrics will appear in the marketplace as fashions change and new textiles are

Table 1. Information about fabrics selected

Fabric	Fiber	Fabric structure	Fabric Count per inch*	Hex per inch*	Width (in)	Source	Type of supplier	Manufacturer	Price/yard ($)
Crepeline, silk	silk	plain weave	76x69		44	Lacis	retail, mail order	unknown	7.92
English net, nylon	nylon	raschel net		17.2x16.0	54	Fabric Place	retail, local	from House of Bianchi	6.98
English net, polyester	polyester	raschel net		18.2x20.8	54	Baer Fabrics	retail, mail order	VDM Distributor	4.75
Georgette, polyester	polyester	plain weave	82x80		40	Fabric Place	retail, local	Pago Fabrics	4.98
Illusion, nylon	nylon	tricot net		14.2x19.4	108	Fabric Place	retail, local	Falk Industries	2.98
Net, nylon	nylon	raschel net		8.5x8.6	72	Fabric Place	retail, local	Falk Industries	0.69
Net, polyester	polyester	tricot net		22.2x16.6	52	Fabric Place	retail, local	from House of Bianchi	4.50
Stabiltex	silk	plain weave	60x61		40	Talas	conservation supply	Schweizerische Seidengaxefabrik AG	41.80
Tulle, cotton - super-fine	cotton	raschel net		24.4x23.5	78	Lacis	retail, mail order	unknown	56.00
Tulle, nylon	nylon	tricot net		15.6x19.7	72	Fabric Place	retail, local	Falk Industries	0.98
Tulle, silk	silk	raschel net		19.3x15.9	72	Berenstein	wholesaler	Alan Litman, Inc.	70.00

* fabric count and hex per inch are reported as warp x filling

Figure 1. Crepeline, silk

Figure 2. English net, nylon

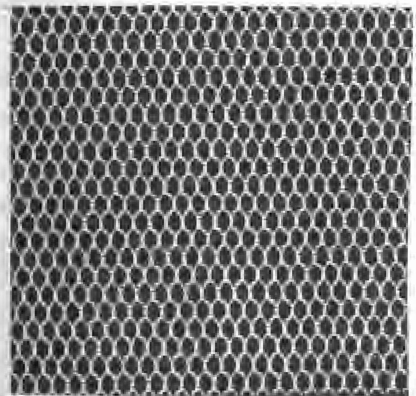

Figure 3. English net, polyester

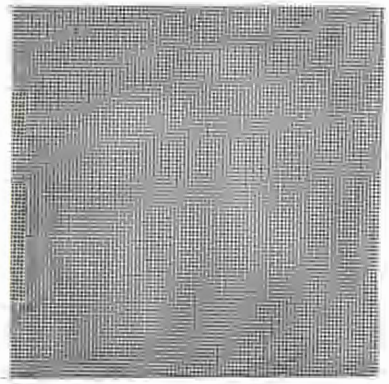

Figure 4. Georgette, polyester

Figure 5. Illusion, nylon

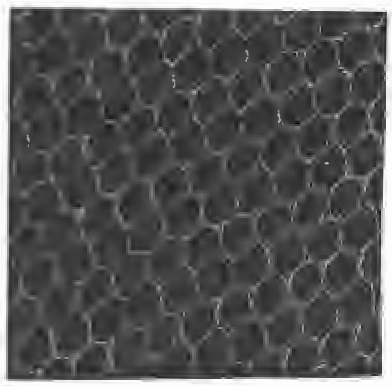

Figure 6. Net, nylon

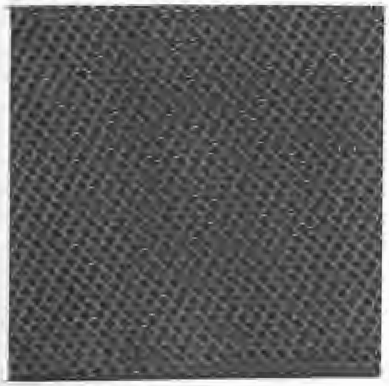

Figure 7. Net, polyester

Figure 8. Stabiltex

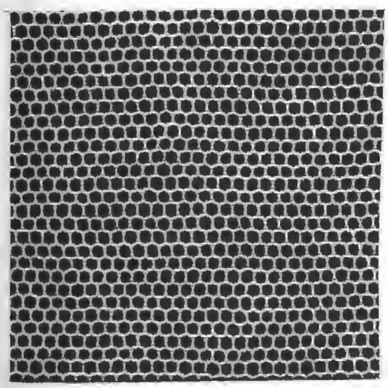

Figure 9. Tulle, cotton

Figure 10. Tulle, nylon

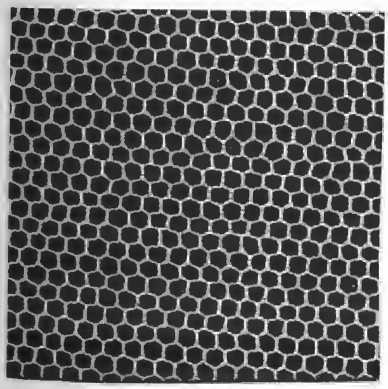

Figure 11. Tulle, silk

developed. These fabrics will need to be evaluated for appropriateness before being used as overlays in conservation.

Because the fabrics in this study were purchased from a variety of retail and wholesale sources, and not all of the retail buyers were willing to give out their sources of manufacture or knew the sources, contacting the manufacturers of all fabrics was not possible. The manufacturer of three of the fabrics (nylon net, nylon illusion, and nylon tulle) stated that he applied a "chemical heat set finish to create a firm hand," but he did not provide further details (Ed Falk, telephone interview, 26 Feb 2004). Information about finishes including the chemical make-up of the finishes and method of application is unknown for the other eight fabrics.

All structural levels, fiber, yarn and fabric, of the textiles were considered during this research. "Fabric is an extremely complex structure for mechanistic analysis. There exist several structural levels from fibers to yarns and eventually to the fabric. Each level has its own geometrical and mechanical variables which control or influence to varying degrees the fabric behavior" (Pan 1996, p 312). Figures 12 to 22 show images of each fabric magnified at 5x except for Figure 17, which is magnified at 2.5x to have an entire hexagon visible in the picture. Three of the fabrics are woven in a plain weave (Figures 12, 15, and 19). The warp knit nets are produced using part-threaded guide bars and altering the overlaps (Figures 13, 14, 16, 17, 18, 20, 21 and 22). In normal warp knitting, every needle must receive at least one overlapped thread, but nets can be produced because the same guide bar does not have to supply every needle, nor does every needle need to be overlapped by the same number of

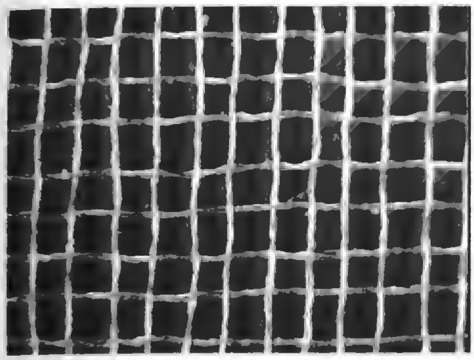
Figure 12. Crepeline, silk (5x)

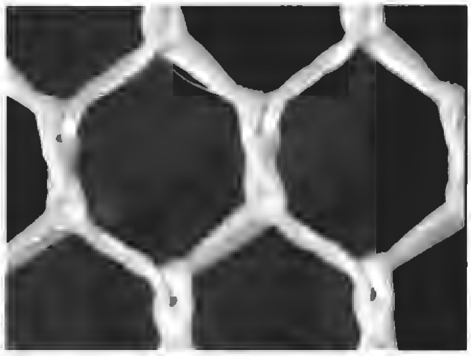
Figure13. English net, nylon (5x)

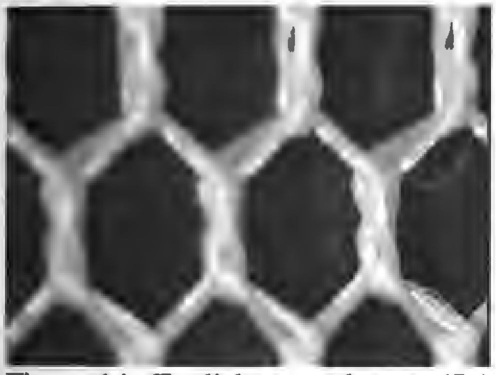
Figure 14. English net, polyester (5x)

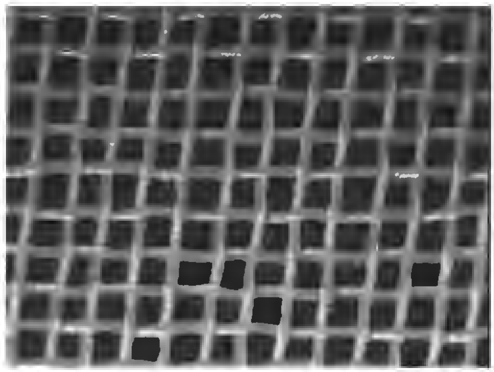
Figure 15. Georgette, polyester (5x)

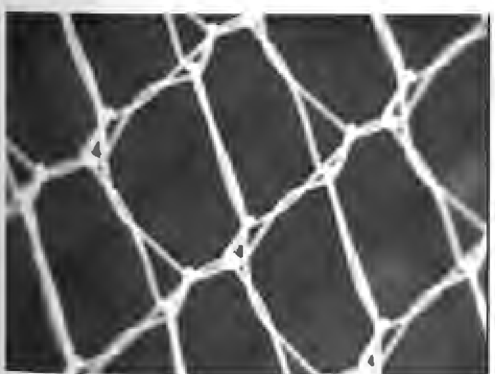
Figure 16. Illusion, nylon (5x)

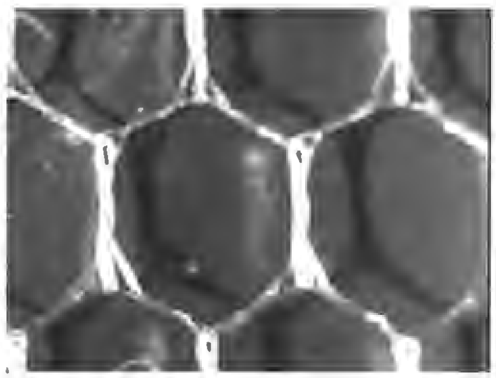
Figure 17. Net, nylon (2.5x)

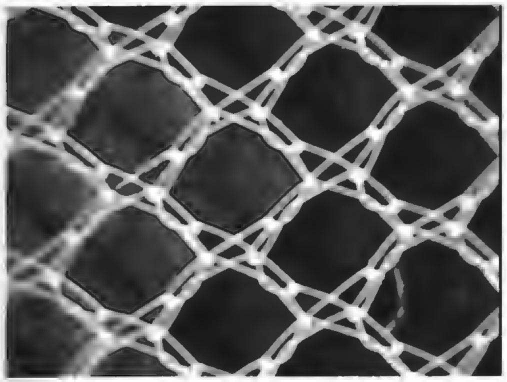

Figure 18. Net, polyester (5x)

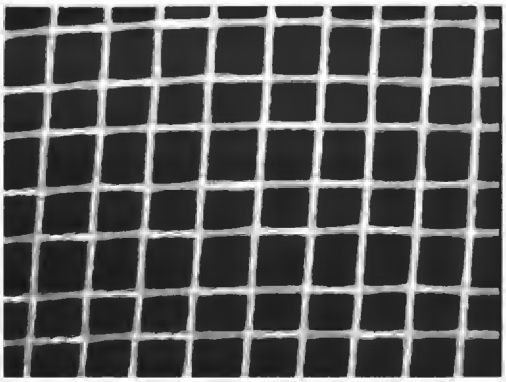

Figure 19. Stabiltex (5x)

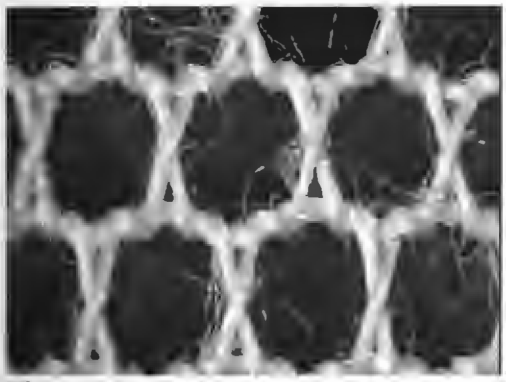

Figure 20. Tulle, cotton (5x)

Figure 21. Tulle, nylon (5x)

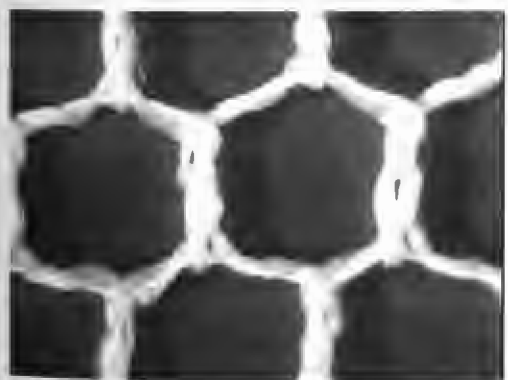

Figure 22. Tulle, silk (5x)

guides. Two identically threaded guide bars that overlap in balanced lapping motions in opposition produce symmetrical nets. Wales are drawn together where underlaps pass across between them, forming net pillars. They separate where no underlaps cross, thus producing openings. A vertical net pillar, as seen in the English nets, is produced as long as the threading repeat of one bar continues to re-cross the same threading repeat in the other bar (see Figures 13 and 14). Openings are finished when one guide bar moves towards another set of threads in the second bar (Spencer 1989 p. 297). Figure 23 illustrates a net with vertical net pillars.

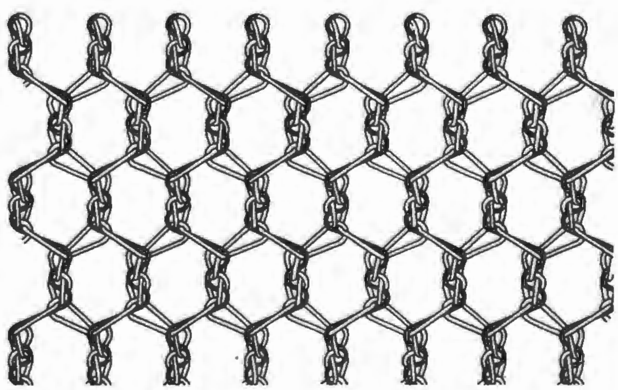

Figure 23. Net structure similar to English nets
(see Figures 13, 14) (Thomas, D.G.B, *An Introduction to Warp Knitting*, Middlesbrough:Merrow, 1976, p. 58)

Fabric names change over time, and fabric suppliers are not consistent in their naming. For example, compare the three tulle fabrics shown in Figures 20, 21, and 22. Two are hexagonal nets; one is a diamond net; and all three have different knit structures, yet all are called tulle. Even consulting the textile experts does not resolve the confusion. Sometimes fiber content is specified in a definition, sometimes weave or knit structure, and sometimes end use. For example, crepeline is defined by Landi as a "fine, plain weave fabric of silk or polyester," by Picken as a "thin lightweight dress fabric of silk or silk mixture," and by Totora as "an exceptionally sheer, plain weave, silk fabric similar to chiffon" (Tortora and Merkel 1996 p. 149; Landi 1998 p. 198; Picken 1985 p. 87). Tulle is defined by *Fairchild's Dictionary of Textiles* as "a net with hexagonal mesh made on a warp knitting machine of silk, cotton or manufactured fiber" (Tortora and Merkel 1996 p. 592). Illusion is a "fine, sheer net fabric" and nylon net is a "sheer net made of nylon" (Picken 1985 p. 182). Figure 24 illustrates a net structure similar to illusion (Fig. 5) and the fabric labeled as nylon tulle (Fig. 10).

The fabric labeled as polyester net (Figure 18) has a structure similar to sand-fly net, which is illustrated in Figure 25. Bobbinet, the fabric name used in the survey, is defined by *Fairchild's Dictionary of Textiles* as a machine-made net with almost hexagonal meshes of twisted cotton or silk yarn, and English net was defined as "a net with hexagonal meshes" (Tortora and Merkel 1996 p. 61, 201). Two of the hexagonal mesh nets used in this research were labeled as English nets by their retailers.

Georgette is defined as "a sheer, lightweight, plain weave silk or manufactured fiber fabric" (Tortora and Merkel 1996 p. 243). Stabiltex is a trade name for a plain woven polyester fabric imported from Switzerland, and its American distributor describes it as "stronger and longer lasting than crepeline." It also is called Terelene and Tetex (Talas, undated p. 73). Care must be taken to avoid confusion when discussing and comparing commercially named fabrics. Retail names of the fabrics plus fiber content are used throughout this research, but identifying them by knit structure and fiber content would be more precise.

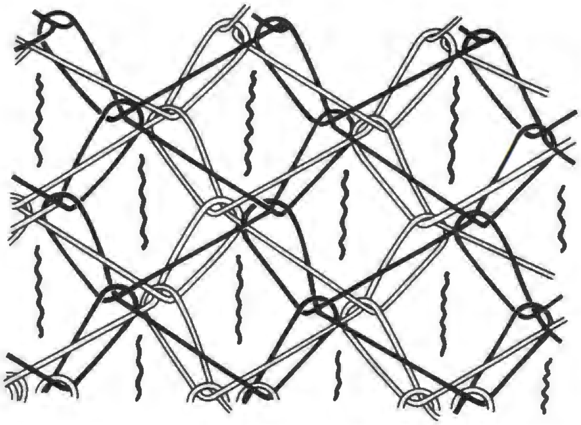

Figure 24. Net structure similar to illusion and nylon tulle (see Figures 16, 21)
(Spencer, David J., *Knitting Technology*, Oxford:Pergamon Press 1989, p. 298)

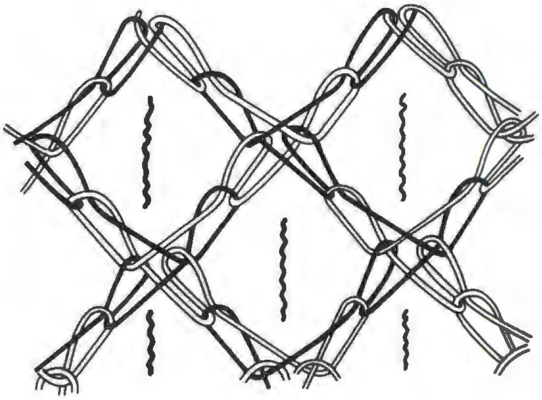

Figure 25. Sand-fly net structure similar to polyester net (see Figure 18)
(Spencer, David J., *Knitting Technology*, Oxford:Pergamon Press1989, p. 298)

The fabrics were purchased in the spring of 2003. They were tested as received from the retail and wholesale sources; they were not washed or pre-treated.

A 100% red cotton flannel was chosen as a fiber donor fabric for the abrasiveness testing based on research done previously by Simpson (1991, 1993). The retailer called it a D/Nap flannel, with a fabric count of 44 x 44 yarns per inch, and it did not have a flame resistant finish. The flannel was washed with ionic and nonionic surfactants in warm water in a standard washing machine and dried in a home dryer prior to being used in the abrasion test.

Yarn Characteristics

A variety of fiber and yarn types make up the fabrics chosen for this research. The yarn characteristics affected the performance of the fabrics and were useful in the analysis. See Table 2 for yarn characteristics. One fabric was made of a cotton yarn with staple-length fibers; two fabrics were of silk multi-filament yarn; three were of polyester multi-filament yarn; one was polyester mono-filament; two were nylon mono-filament and two were nylon multi-filament. Of all the synthetic fibers, only the nylon in the nylon net fabric did not have delustrant added.

Yarn denier, a measurement of linear density, was obtained from the retailer or the manufacturer when possible. When it was not available denier for the woven fabrics was calculated by weighing three one meter long yarn samples in both the warp and filling directions to 0.0001 gm and then multiplying the mean of those samples by 9,000. Obtaining one meter samples from the weft direction of silk crepeline or the knitted nets was not possible, but shorter yarn samples were unraveled, measured, and weighed. Weights were scaled up to the weight of one meter and

Table 2. Yarn characteristics of overlay fabrics

Fabric	Yarn Denier, Warp	Yarn Denier,** Filling	Fiber	Luster	Yarn type	Yarn Diameter, Warp (mm)	Yarn Diameter, Filling** (mm)	Yarn spin	Filament Diameter (microns)	Yarn Cross Section	Other
Crepeline, silk	19.2*	9.6*	silk	-	multi-filament	0.05	0.09	medium	0.1 - 0.15	-	
English net, nylon	84*		nylon	delustered	multi-filament	0.2		medium	15	cylindrical	
English net, polyester	50		polyester	delustered	multi-filament	0.2		none	14.5	cylindrical	
Georgette, polyester	50	50	polyester	delustered	multi-filament	<0.1	0.1	high	15	cylindrical	
Illusion, nylon	15		nylon	delustered	mono-filament	0.045		none	45	cylindrical	chemical heat-set finish
Net, nylon	40		nylon	bright	multi-filament	0.2		none	15	tri-lobal	chemical heat-set finish
Net, polyester	90*		polyester	delustered	mono-filament	0.048		none	47.5	cylindrical	
Stabiltex	22.5*	27.6*	polyester	delustered	multi-filament	<0.1	<0.1	low	44	cylindrical	
Tulle, cotton	81*		cotton	-	staple	0.1		medium	-	-	un-mercerized
Tulle, nylon	15		nylon	delustered	mono-filament	0.045		none	45	cylindrical	
Tulle, silk	#		silk	-	multi-filament	0.12		none	0.1 - 0.15	-	chemical heat-set finish

* calculated
** yarn denier and yarn diameter for knitted fabrics is given in the warp column only
# unable to obtain sample large enough to calculate denier

denier was calculated by multiplying by 9,000. Because the samples were very small, accuracy was compromised.

The deniers from the retailers and manufacturers were for yarns prior to the application of any finishing. The calculated deniers are from fabrics that may have applied finishes, and a finish could affect the weight of the yarns and affect accuracy. Because of these discrepancies, denier is reported in Table 2, but it is not used in any of the analyses. Normally cotton count would be reported for a cotton yarn, but to facilitate comparisons in this research, the cotton yarn linear density also is reported as denier.

Other yarn characteristics such as luster, yarn type, spin, and yarn cross-section were determined using microscopes located in the Textiles, Fashion Merchandising and Design Department at the University of Rhode Island. Image-Pro Plus, version 4.5 for Windows, by Media Cybernetics, Inc. was used to measure yarn and filament diameter.

Fabric Structure

The fabric structure of the sheer overlays affected performance test results. Three of the fabrics—silk crepeline, polyester georgette, and polyester Stabiltex—are woven fabrics with a plain weave structure. The other eight fabrics are warp knits. Thomas stated that the physical properties of a warp knit are a function of its structure. In this, it differs from weft knits and woven fabrics (Thomas 1976). Three were knit on tricot machines; the other five were knit on raschel machines.

Either tricot or raschel machines can produce knit meshes, depending on the complexity, yarn size and end use (Kadolph and Langford 1998). Falk Industries, the manufacturer of the nylon tulle, described it as a tricot fabric. The buyer at Baer fabrics described the polyester English net as a tricot fabric. The polyester net, from an unknown manufacturer, unraveled similarly to a tricot knit under close examination. See Figure 25 for an illustration of its structure. The complex structure of the other five fabrics defines them as raschel knits. Nylon illusion, polyester net, and nylon tulle are diamond mesh nets; the polyester net is similar to a net described by Spencer (1989) as a sand-fly net. Cotton tulle, silk tulle, nylon net, and the two English nets are hexagonal mesh nets. The Tortora and Merkel (1996) definition of tulle as a net with a hexagonal mesh, would label the two English nets, seen in Figures 13 and 14, as a tulle structure, despite their marketing names (p. 592). The nylon tulle, due to its diamond mesh seen in Figure 21, would not fit this definition of tulle. The nylon net does not have the knit pillar structure of a typical bobbinet, but the cotton and silk tulles and the English nets both have the pillar structure (see Figures 13,14,17, 22). The relative stability or stretch of a warp knit fabric can be altered by control of the knitting stitch (Kadolph and Langford 1998). The diamond mesh nets in Figures 16 and 21 have different yarn interlacement and stretch properties than the hexagonal mesh nets in Figures 13, 14, 17, 20, and 22. The illustrations in Figures 23 – 25 show these differences clearly. The polyester net, which is similar to the sand-fly net pictured in Figure 25, may have unique properties due to its yarn arrangement.

Finishes may have been applied to the fabrics, but because they were obtained primarily at retail establishments, full information on finishes is not available.

According to the manufacturer, three of the fabrics—nylon net, nylon illusion, and nylon tulle—do have a "chemical, heat set finish to create a firm hand" (Ed Falk, telephone interview, 26 Feb 2004). According to Spencer, "there is considerable potential for changing the fabric properties during the finishing process as well as during knitting" (Spencer 1989 p. 40). A manufacturer's finish can change the hand of warp knits; it can add stiffness or softness a fabric. Often anti-static agents may be included in the finishing process (Thomas 1976). This lack of knowledge about fabric finishes prevents analysis of their effect on various properties.

Standard Testing

A sampling plan was created, and test samples were cut using a rotary cutter and mat. Fabrics were conditioned in the conditioning room at 70°±2° and 65%±2% relative humidity for 24 hours prior to each test according to ASTM D 1776-98 (ASTM 2003). Testing was randomly assigned to samples. All standard testing was done in the Textile Performance Laboratory at the Department of Textiles, Fashion Merchandising and Design at the University of Rhode Island.

Standard tests from ASTM, International were used for basic textile descriptive tests such as thickness, weight, and fabric count. Standard tests were used whenever available to test the fabric properties important to conservators who use sheer fabrics. Non-standard tests were employed when standard tests did not exist to measure other

Standard Test Method for Thickness of Textile Materials, ASTM D 1777-96, was used. Measurements were taken at ten different locations on each uncut fabric to 0.0001 inch. Mean thickness was calculated for each fabric, converted to and reported in microns (ASTM 2003).

Fabric weight was tested using ASTM D 3776-96, Standard Test Method for Mass Per Unit Area (Weight) of Fabric. Weighing was done to 1.0 mg in the textile conditioning room at the University of Rhode Island. Four samples were weighed; mean weights were calculated and converted to grams per square meter of fabric and ounces per square yard (ASTM 2003).

Fabric count was measured for the woven fabrics using ASTM D 3775-03 Standard Test Method for Warp End Count and Filling Pick Count of Woven Fabric (ASTM 2003). Fabric count was measured in both the warp and filling directions and reported as yarns per inch. The knitted fabrics in this research were all net-like structures, some tricot knits and some raschel knits. Fabric count for the knitted fabrics was measured by counting the hexagonal or diamond shaped openings per linear inch using methods similar to those for woven fabric in ASTM D 3775-03. Hex per inch was counted in both a vertical and horizontal direction, and the results are reported as warp for the vertical count and filling for the horizontal count. Three positions on each fabric were measured, and means were calculated.

Electrostatic cling was tested using AATCC Test Method 115-1995, Electrostatic Clinging of Fabrics: Fabric-to-Metal Test. Three samples of each fabric were tested by rubbing with 100% spun nylon 6,6 fabric (Testfabrics 2003). Tests were conducted in the conditioning room. Cling times were measured to a second, and mean cling times were calculated (AATCC 2003).

ASTM D 6614-00, Standard Test Method for Stretch Properties of Textile Fabrics – CRE Method was used to measure the stretch and growth of the sheer fabrics. A CRE-type tensile testing machine, Q-Test I running Testworks QT 2.02 software, was used. This machine is located in the conditioning room at the University of Rhode Island. A load of 4 lbs. was chosen, and fabrics were extended at a slow speed. This test was chosen over other stretch tests because both woven and knitted fabrics were involved and because none of the fabrics included a stretch or elastomeric yarn. Two samples of each fabric were tested. Two of the fabrics broke during testing, so complete results were not obtained. Mean rates of stretch and growth were calculated (AATCC 2003). Strength and stability of fabrics can be indirectly assessed using this method when they break under the load imposed for this test.

Fabric stiffness and fabric hand were tested using ASTM D 1388-96, Standard Method for Stiffness of Fabrics. Bending length was measured to 0.1 cm on a cantilever bending tester. Four samples of each fabric were tested. Stiffness was measured in both the warp and filling directions. Means for stiffness were calculated (ASTM 2003).

Non-Standard Testing

Cover

Cover is "the ratio of fabric surface occupied by yarn to the total fabric surface." It is sometimes called the cover factor. Cover may be calculated for woven fabrics when warp and filling yarn diameters and fabric count are known (Kaswell 1963 p. 450). The structure of knitted nets makes a straightforward geometrical calculation of cover very difficult. Digital imaging software was used in this research to provide a measure of cover that allowed comparison of cover factor between knitted and woven fabrics. Image-Pro Plus, version 4.5 for Windows, by Media Cybernetics, Inc. was used to analyze the percent area covered by each fabric (Media-Cybernetics 2002). Fabrics were scanned using a Hewlett Packard 1200 series scanner at 1200 dpi with dark purple Pantone paper #19-3714 as background. HP Director 7.1.4 was used to digitize and save the images.

A one-square-inch area of interest was defined at random on each scanned image. The Image-Pro software measured the percent area of white fabric for each area of interest. Three areas of interest were defined and measured for each fabric sample. Mean percent area was calculated for each fabric. This measure allowed the eleven fabrics to be compared to one another for area covered or conversely for the amount of background that shows. This measure was not compared to calculated cover factor for individual woven fabrics, but in a situation where fabrics are ranked most cover to least cover, it should provide a similar ranking. Digital imaging makes the measurement of cover for complex fabric structures such as knits possible. This method of measuring cover is easier to do and may prove to be a better method for comparisons than the calculated method.

Gloss

Gloss measurements were performed by Bossa Nova Tech, a company specializing in non-destructive testing instruments, located in Venice, California. Bossa Nova Tech used the Samba Advanced Vision System. The Samba Live Gloss Measurement software calculates "the average gloss degree in a Region of Interest." The Samba system uses an Analog PAL sensor video format; with a 9-hertz refresh rate, a resolution of 768 x 576 and one half-inch CCD type. The spectral bandwidth is 400-700 nm, and the gloss degree measurement ranges from 0 – 100%, with a degree of accuracy within 0.5%, and a scattering contrast ratio of 100 (Breugnot 2003). Results were reported in gloss degree percentage. Three areas on each fabric sample were tested, but results were received as single values, so no statistical testing was done as replicate test scores were not available.

Coefficient of Friction and Surface Roughness

Two tests, surface roughness and coefficient of friction, were measured on the Kawabata Evaluation System (KES) to evaluate hand. The system combines tests for tensile, shearing, pure bending, compression, and surface roughness characteristics. It also tests the coefficient of friction on fabric surfaces (KatoTech 2004). The Kawabata test is not recognized as a standard test by AATCC or ASTM but is used in textile research when quantitative data on the handle of fabric is required (Kawabata 1980; Collier and Epps 1999). Friction is the ability of a fabric to move along another surface and may be affected by surface roughness and fabric structure. Surface roughness is defined as the "deviation in thickness on the surface as a result of the structure" of a fabric (Scruggs 2004). Surface roughness is measured in microns, so a larger SMD indicates a greater geometric fabric roughness. Surface friction and roughness were measured by the KES by putting a 0.5 mm diameter U-shaped steel piano wire in contact with the fabric surface. The coefficient of friction is measured with a single wire with a contact force of 10 g. The surface roughness test used ten aligned wires and a compressional force of 50 g. The specimen fabric moved horizontally on a steel plate under constant tension at a constant velocity of 0.1 cm/sec. The up-and-down movement of the detector wires was used to calculate surface roughness in microns. Mean values of coefficient of friction and the mean deviation of friction were calculated. Mean deviation of surface roughness also was calculated. Samples were tested in both warp and weft directions. A grand average, which is the average of the warp and filling directions, was automatically calculated (Kawabata 1980). Development of the KES allowed researchers to "relate objective measurement of the important properties in fabric hand to subjective evaluation" (Collier and Epps 1999 p. 269).

The KES owned by North Carolina State University, College of Textiles, was used in this research to measure the coefficient of friction and the surface roughness of the sheer fabrics. Barbara Scruggs, Ph.D. and her colleagues ran the samples through their KES. They performed three replications of each test on each fabric. Dr. Scruggs commented on the interpretation of the data:

> The coefficient of friction (MIU) is a value between 0 and 1 and indicates the amount of resistance/drag sensed by the probe as it moves across the fabric surface. A higher value indicates greater friction. This result is

> largely associated with amount of contact area the probe makes with the fabric surface. The greater the contact, the higher the MIU. Therefore, this result is sometimes inconsistent with expectations. For example, very soft fabrics may feel smooth and slippery between the fingers when you feel them, but you may get a higher MIU than with a stiff fabric because the probe may press into a soft fabric, almost becomes imbedded, and result is a high contact area/higher MIU. Stiff, rough fabrics may have lower MIU than expected because stiffness prevents the probe from making total contact with the fabric surface. (Scruggs 2004)

Many of the fabrics tested in this research were stiff, and the nets had large spaces between yarns that may have increased the surface roughness and changed the contact area of the probe. Results were interpreted considering this caution.

Abrasiveness

Most of the large body of research on abrasion in textiles investigated abrasion resistance, not abrasiveness. Seven standard tests measure abrasion resistance in fabrics using various mechanical means to abrade the textile to a breaking point. These tests include: ASTM D 3884-92 Abrasion Resistance of Textile Fabrics (Rotary Platform, Double-Head Method), ASTM D 3885-92 Abrasion Resistance of Textile Fabrics (Flexing and Abrasion Method), ASTM D 3886-92 Abrasion Resistance of Textile Fabrics (Inflated Diaphragm Method), ASTM D 4157-92 Abrasion Resistance of Textile Fabrics (Oscillatory Cylinder Method), ASTM D 4158-92 Abrasion Resistance of Textile Fabrics (Uniform Abrasion Method), ASTM D 4966-89 Abrasion Resistance of Textile Fabrics (Martindale Abrasion Tester Method), and AATCC 93 Abrasion Resistance of Fabrics (Accelerotor Method). None of these tests uses fabric-to-fabric abrasion, and all of them use a high force to abrade the test fabric to a hole or break. The following crocking and frosting tests also simulate abrasion: AATCC 8-1996 Color Fastness to Crocking (Crockmeter Method), AATCC 116-1996 Color Fastness to Crocking (Rotary Vertical Crockmeter Method), AATCC 119-1996 Color Change Due to Flat Abrasion (Frosting: Screen Wire Method), AATCC 120-1996 Color Change Due to Flat Abrasion (Frosting: Emery Method) (Collier and Epps 1999).

Simpson (1991, 1993) used a crockmeter and a variation of the standard crocking test to simulate low-force fabric-to-fabric abrasion such as might occur in museum display or storage conditions. Annis went a step further and created a testing machine to simulate low-force fabric-to-fabric abrasion. See Figure 26. This machine, the ABD Materials Evaluator, does orbital and linear abrasion and uses light loads (≤600g and ≥800 g., 0.05 psi) at slow speeds (3-44 rpm) with controlled tension

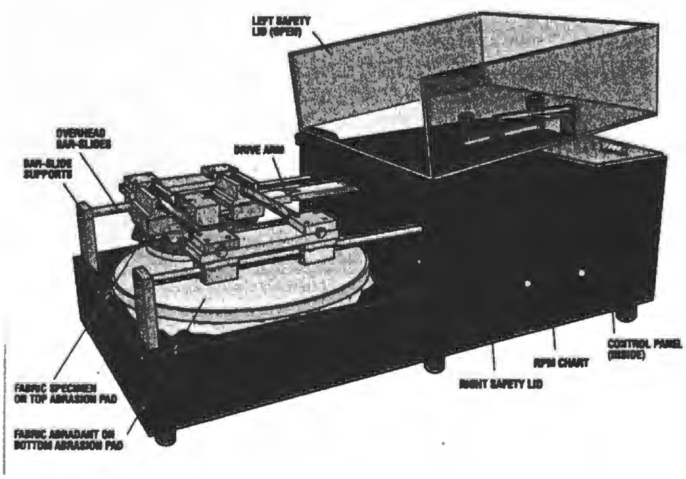

Figure 26. ABD Materials Evaluator

on both fabrics and control over specimen and abradant orientation (Annis 2000). Standard test status for the ABD Materials Evaluator has been applied for and is pending approval of ASTM subcommittee D-13.60 (Annis 2001).

Pre-testing in this research by this author used Simpson's crockmeter method, but the review of literature indicated that better control over the test conditions could be obtained by using the instrument designed by Annis and colleagues. Therefore, this researcher used the ABD Materials Evaluator for the actual research, located at the University of Georgia, Department of Textiles, Merchandising, and Interiors, Athens, Georgia, illustrated in Figure 26. Fabrics were conditioned at 70°±2° F and 65%±2% relative humidity for 24 hours, prior to testing according to ASTM D 1776-98 Standard Practice for Conditioning and Testing Textiles (ASTM 2003). Testing was conducted according to the ABD Materials Evaluator operator's manual and the proposed standard test method (Annis, Bresee, and Davis undated; Annis 2001). The sheer overlay fabric samples were placed on the lower pad, on top of a piece of 100% cotton undyed print cloth. A fiber-donor fabric, red 100% cotton flannel similar to that used by Simpson in her research, was placed on the upper pad (Simpson 1991, 1993). After pre-testing several combinations of load, speed, cycles, and orientation, this researcher chose 40 rpm, 800 ± 30 g load, and 50 cycles of orbital abrasion. While lower speed, load, cycles, and linear direction would better simulate actual abrasion in display and storage settings, they did not show enough released fibers for adequate digital image analysis. These conditions are still low compared to those used in the standard test method tests for abrasion resistance. Three replications were done for each test fabric. Test samples were packed carefully for transportation back to the University of Rhode Island for digital image analysis.

Three, randomly selected, 2-inch square areas of each test fabric were scanned on an Epson Perfection 1200 Photo scanner at 1200 dpi. IrfanView 3.85 was used to digitize and save the images. Thus nine images of each fabric were available for analysis. Image-Pro Plus, version 4.5 for Windows, made by Media-Cybernetics, Inc. was used to analyze the area of red cotton flannel fibers left on the test fabrics after abrasion on the ABD Materials Evaluator (Media-Cybernetics 2002). The count/size function was used to highlight each red fiber in the image. Addition of various filters seemed to increase the likelihood that shadows would be counted as fibers. The data used were from unfiltered images. Data were reported as area (mm^2) of red fiber left on the overlay fabric after abrasion.

The digital imaging software also counted the number of fibers, fiber fragments, and fiber clumps as objects, but some samples had large clumps of fiber, while others had only small individual fibers and fiber fragments. The software could not distinguish objects by size. Control of fragment size is necessary before count will accurately reflect the amount of fiber left on the overlay after abrasion. Count data were not used in the statistical analysis but are shown graphically in the results section.

Statistical Analysis

The null hypothesis of the research was that overlay fabrics do not differ in abrasiveness. Raw data were recorded in an Excel spreadsheet and input electronically into Statistical Package for the Social Sciences (SPSS) version 11.5 for Windows program owned by the Department of Nutrition and Food Science at the University of Rhode Island. Means and standard deviations were calculated. All statistical tests will be two-sided and performed at the $\alpha = 0.05$ significance level, unless specified otherwise. One-way analysis of variance (ANOVA) was done to enable comparison of each fabric to every other fabric for all tests. If the ANOVA indicated a significant difference overall between at least two fabrics, then Tukey's Honestly Significant Difference (HSD) test was performed to identify homogenous subsets. Statistical correlation coefficients were calculated between selected pairs of variables in the data set. Spearman's rho was used because the data for at least one of the variables in every pair could not be considered to be normally distributed. A correlation coefficient is only a measure of the linear relationship that exists between two variables, and a cause and effect relationship between them should not be inferred since other unidentified variables could be affecting either or both of the variables.

CHAPTER 4

RESULTS AND DISCUSSION

Performance testing of textiles provides data by which the textiles can be compared. This research gathered objective data to be used specifically for comparison of the various fabrics used as sheer overlays in textile conservation. The results of standard descriptive tests such as fabric weight, thickness, and fabric count as well as non-standard descriptive tests such as gloss and cover factor are presented here. Tests describing the mechanical properties of the sheer overlay fabrics also are presented in this section. Results from standard tests for elongation, electrostatic cling, and stiffness as well as non-standard tests such as abrasiveness, cover, coefficient of friction, and surface roughness are presented and discussed in this section.

Physical Properties of Fabrics

Weight

All of the fabrics were very lightweight. Four samples of each fabric were weighed and the results averaged. Polyester English net and polyester georgette, both raschel knits, had the highest weight per unit area at 45.99 gm/m^2 and 43.86 gm/m^2 respectively; nylon tulle and nylon illusion had the least at 8.93 gm/m^2 and 8.80 gm/m^2 respectively. See Figure 27. These latter two are made with mono-filament yarn and are tricot knits as seen in Figures 16 and 21. The third mono-filament, polyester net, fell in the mid-range of weights. The one fabric made from a staple fiber, cotton tulle, was at the high end of the range. The polyester fabrics, with the exception of mid-weight Stabiltex, were in the top half of the sample for weight; the nylon fabrics, with the exception of nylon English net, were in the bottom half of the sample for weight.

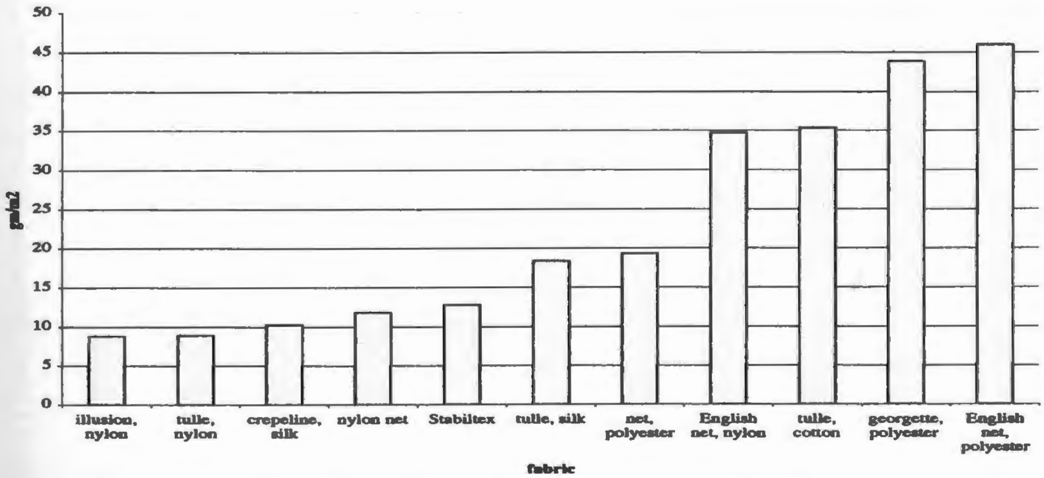

Figure 27. Weight (gm/m^2) of overlay fabrics

One-way analysis of variance (ANOVA) was performed on the overall mean weights of the eleven fabrics to determine the existence of significant differences between at least two fabrics. The ANOVA showed significant differences existed between at least two fabrics ($p \leq 0.01$) in the weights of the fabrics, therefore Tukey homogeneous subset (HSD) analysis was done. Tukey's HSD method produced seven statistically significantly different groups (not necessarily mutually exclusive) from the eleven fabrics. Table 3 displays the seven groups. The heading "sig" denotes the p-value (significance probability) of the non-significant pair-wise ($p>0.01$)

Table 3. Fabric weight, Tukey's homogeneous subsets (alpha = 0.05)

Group	Sig	Least	Nylon illusion	Nylon tulle	Silk crepeline	Nylon net	Stabiltex	Silk tulle	Polyester net	Nylon English net	Cotton tulle	Polyester georgette	Polyester English net	Most
1	1.000		—	—										
2	0.103			—	—									
3	0.400					—	—							
4	0.505							—	—					
5	0.895									—	—			
6	1.000											—		
7	1.000												—	
Fiber			nylon	nylon	silk	nylon	polyester	silk	polyester	nylon	cotton	polyester	polyester	
Fabric structure			tricot	tricot	woven	raschel	woven	raschel	tricot	raschel	raschel	woven	raschel	
Yarn			mono	mono	multi	multi	multi	multi	mono	multi	staple	multi	multi	

comparisons of the mean weights. Low p-values indicate that the mean weights of the fabrics in a group have a larger separation than those with high p-values. In fact, the p-value of 1.000 for nylon illusion and nylon tulle, group 1, indicates that their mean weights are statistically equal. The mean weights of nylon tulle and silk crepeline in group 2 have the greatest separation—lowest of the p-values, $p=0.103$, (but still not significantly different)—across all of the seven groups. Nylon tulle is in group 1 and group 2, meaning that its mean weight is not significantly different from nylon illusion (group1) or silk crepeline (group 2), but the mean weights of the latter two are significantly different. Groups 3 through 5 are composed of two fabrics each that are not significantly different, and groups 6 and 7 consist of single fabrics.

When weight was paired with other variables using Spearman's correlation coefficient, it was positively correlated with thickness ($r=0.687$; $p=0.01$), cover ($r=0.825$; $p=0.01$), and fabric count in the warp direction ($r=0.376$; $p=0.05$). It was not significantly correlated with fabric count in the filling direction. Weight was negatively correlated with stiffness in the warp ($r=-0.779$; $p=0.01$) and filling ($r=-0.715$; $p=0.000$) directions. Additional information to facilitate the interpretation of these results is found in later sections of this paper.

Thickness

Of the six thickest fabrics, all but one were raschel knits; the English nets were the two thickest fabrics at 330.2 microns for the nylon English net and 336.55 microns for the polyester English net. The tricot knit polyester net also fell within the top six at 303.02 microns. The two thinnest fabrics were wovens: silk crepeline at 91.44

microns and Stabiltex at 92.71 microns. See Figure 28. These results show that fabric structure affects thickness in these sheer overlay fabrics.

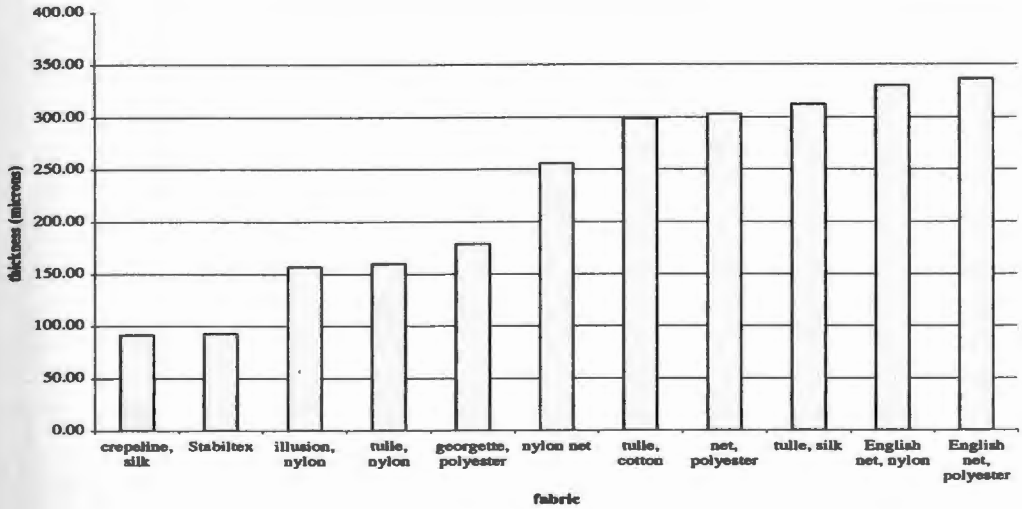

Figure 28. Thickness of overlay fabrics

A one-way ANOVA was performed on the overall mean thicknesses of the eleven fabrics to determine the existence of significant differences between at least two fabrics, and it showed that significant differences existed at the ($p<0.01$). Therefore, the data were analyzed by Tukey's HSD method. This analysis method produced six statistically significantly different subsets (not necessarily mutually exclusive) from the eleven fabrics as shown in Table 4. The two thinnest fabrics, silk crepeline and Stabiltex, were significantly different from the other fabrics, and with a p-value of 1.000, their mean thicknesses are statistically equal. The next two thinnest, nylon illusion and nylon tulle, also had statistically equal thicknesses and were significantly different from all of the other fabrics. Polyester georgette and nylon net are in the mid-range for thickness and are each significantly different from all other

Table 4. Fabric thickness, Tukey's homogeneous subsets (alpha = 0.05)

Group	Sig	Least	Silk crepeline	Stabiltex	Nylon illusion	Nylon tulle	Polyester georgette	Nylon net	Cotton tulle	Polyester net	Silk tulle	Nylon English net	Polyester English net	Most
1	1.000		—	—										
2	1.000				—	—								
3	1.000						—							
4	1.000							—						
5	0.057								—	—	—			
6	0.906											—	—	
Fiber			silk	polyester	nylon	nylon	polyester	nylon	cotton	polyester	silk	nylon	polyester	
Fabric structure			woven	woven	tricot	tricot	woven	raschel	raschel	tricot	raschel	raschel	raschel	
Yarn			multi	multi	mono	mono	multi	multi	staple	mono	multi	multi	multi	

fabrics. The two English nets—polyester and nylon—are the thickest fabrics and are significantly different from all the other fabrics, but their p-value of 1.00 indicates that they have statistically equal thicknesses. The nylon English net is the heaviest and the thickest fabric in the research.

Statistical correlation coefficients were calculated, using Spearman's rho, between selected pairs of variables in the data set. When thickness was paired with the other variables, it was positively correlated with fabric weight ($r=0.687$; $p=0.01$). The heaviest fabric, the polyester English net also was the thickest fabric. Thickness was positively correlated with surface roughness in both the warp ($r=0.607$; $p=0.01$) and the filling ($r=0.604$; $p=0.01$) directions. In the warp direction, the two thickest fabrics—polyester English net and nylon English net—have the highest surface roughness. This may indicate that fabric structure is a variable that affects both thickness and roughness. Thickness also was positively correlated with filling stretch ($r=0.516$; $p=0.050$) and filling growth ($r=0.434$; $p=0.050$), but not significantly correlated with warp stretch or growth. Thickness was negatively correlated with stiffness, meaning that as thickness decreased stiffness increased: warp ($r=-0.312$; $p=0.01$), filling ($r=-0.587$; $p=0.01$). The English net fabrics, ranked at the high end of the thickness scale and near the low end of the stiffness scale, demonstrate this negative correlation. Fabric finishing often controls the variable of stiffness, and incomplete data about finishes on the fabrics in this research make interpretation of this correlation inconclusive.

Fabric Count

Fabric count was measured as yarns per inch for the woven fabrics and hex per inch for the knitted nets. The nylon net had the lowest hex per inch count, (warp 8.55, filling 8.6) meaning that the interstices between the yarns were larger than for the other nets. Cotton tulle had the highest hex per inch count at 24.4 in the warp direction and 23.5 in the filling direction. The nets made of nylon had the four lowest hex per inch counts. Type of knit, raschel versus tricot, did not seem to influence the hex per inch measurement. Cotton tulle is available in a variety of hex per inch sizes; the one used here was labeled "super-fine." Figure 29 shows the hex per inch measurements graphically.

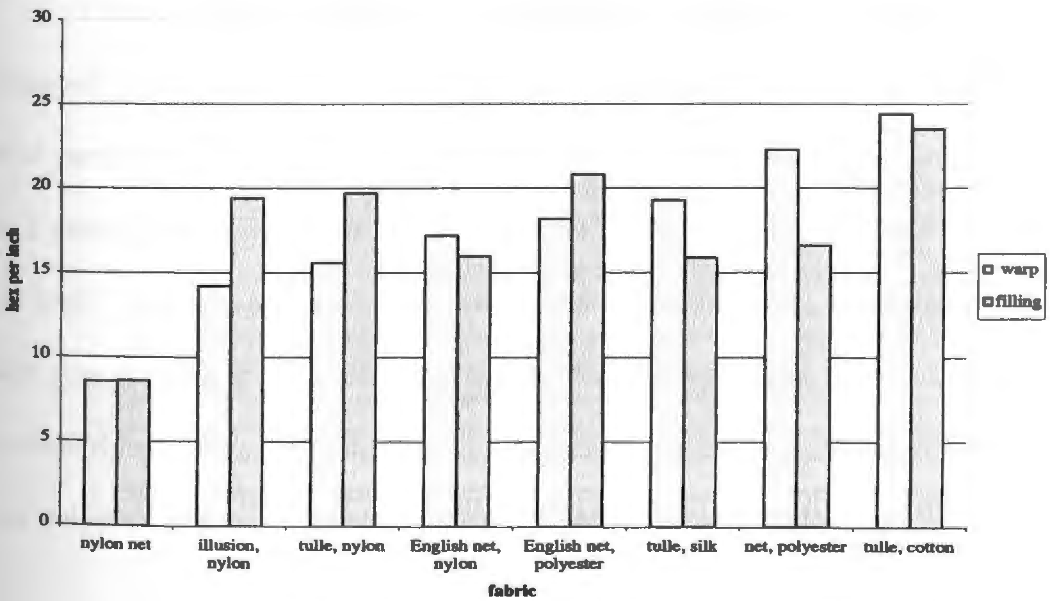

Figure 29. Fabric count, knitted nets (hex per inch)

One-way ANOVA comparing the means of all eleven fabrics indicated a significant difference between at least two fabrics at $p < 0.01$. Tukey's HSD method, based on comparing means for both woven and knit fabrics produced ten statistically significantly different groups (not necessarily mutually exclusive) in the warp direction and seven different groups in the filling direction from the eleven fabrics. See Tables 5 and 6. The analysis indicated that nylon net was significantly different from all the other fabrics, in both warp and filling directions. At the high end of the range, polyester net and cotton tulle were significantly different from each other and all the other fabrics in the warp direction. Cotton tulle also was significantly different from all fabrics in the filling direction. The greatest separation of means occurred in the three fabric grouping of nylon illusion, nylon tulle, and nylon English net in the filling direction at $p=0.058$.

Figure 30 shows the fabric counts for the woven fabrics. All three are balanced plain weave. The polyester georgette had the highest fabric count at 82.0 x 80.4 yarns per inch. The polyester Stabiltex had the lowest fabric count of 60.0 x 61.2 yarns per inch, while the silk crepeline was in the middle with 76.0 x 69.6 yarns per inch. The yarns in these fabrics are fine (<0.1 mm diameter), and therefore the high yarn count does not make a stiff fabric. The amount of yarn spin varied greatly in these three fabrics: Stabiltex had very low spin, silk crepeline had medium spin, and polyester georgette had high spin. See Table 2 for yarn denier data.

Table 5. Fabric count, warp, Tukey's homogeneous subsets (alpha = 0.05)

Group	Sig	Lowest	Nylon net	Nylon illusion	Nylon tulle	Nylon English net	Polyester English net	Silk tulle	Polyester net	Cotton tulle	Stabiltex	Silk crepeline	Polyester georgette	Highest
1	1.000		—											
2	0.375			—	—									
3	0.203				—	—								
4	0.811					—	—							
5	0.710						—	—						
6	1.000								—					
7	1.000									—				
8	1.000										—			
9	1.000											—		
10	1.000												—	
Fiber			nylon	nylon	nylon	nylon	polyester	silk	polyester	cotton	polyester	silk	polyester	
Fabric structure			raschel	tricot	tricot	raschel	raschel	raschel	tricot	raschel	woven	woven	woven	
Yarn			multi	mono	mono	multi	multi	multi	mono	staple	multi	multi	multi	

Table 6. Fabric Count, filling, Tukey's homogeneous subsets (alpha = 0.05)

Group	Sig	Lowest	Nylon net	Silk tulle	Nylon English net	Polyester net	Nylon illusion	Nylon tulle	Polyester English net	Cotton tulle	Stabiltex	Silk crepeline	Polyester georgette	Highest
1	1.000		—											
2	0.844			—	—	—								
3	0.058						—	—	—					
4	1.000									—				
5	1.000										—			
6	1.000											—		
7	1.000												—	
Fiber			nylon	silk	nylon	polyester	nylon	nylon	polyester	cotton	polyester	silk	polyester	
Fabric structure			raschel	raschel	raschel	tricot	tricot	tricot	raschel	raschel	woven	woven	woven	
Yarn			multi	multi	multi	mono	mono	mono	multi	staple	multi	multi	multi	

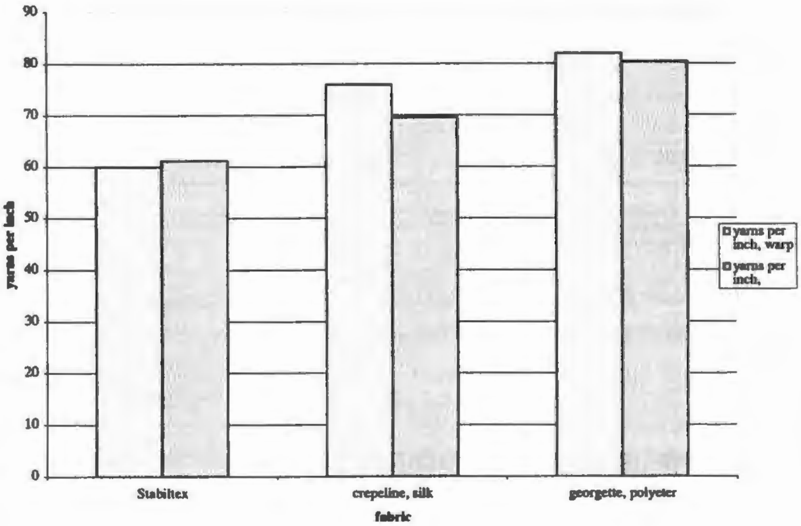

Figure 30. Fabric count, woven fabrics (yarns per inch)

Comparison of means by Tukey's HSD indicated that all three woven fabrics are significantly different from each other and from all the knitted fabrics in both the warp and filling directions. See Tables 5 and 6.

Fabric count was paired with the other variables using Spearman's rho correlation. Fabric count in the warp direction was positively correlated with fabric count in the filling direction (r=0.770; p=0.01). Warp-wise fabric count was positively correlated with weight (r=0.376; p=0.01) and cover (r=0.607; p=0.01). It was negatively correlated with stretch, growth, coefficient of friction, surface roughness, abrasiveness, and electrostatic cling. Fabric count in the filling direction was positively correlated with cover (r=0.483; p=0.01) and negatively correlated with thickness, stretch, growth, coefficient of friction, surface roughness, abrasiveness and electrostatic cling. See Table 7.

Cover

As measured by digital imaging software, woven polyester georgette, with its high fabric count, had the highest percent cover at 54.26% and was, therefore, the least sheer. See Figure 31. The cotton tulle, with its fuzzy staple-length fibers partially covering the interstices, and a high hex-per-inch count was the second least sheer at 34.98%. Nylon net had the lowest percent cover at 8.11% and was the most sheer. Nylon tulle and nylon illusion,

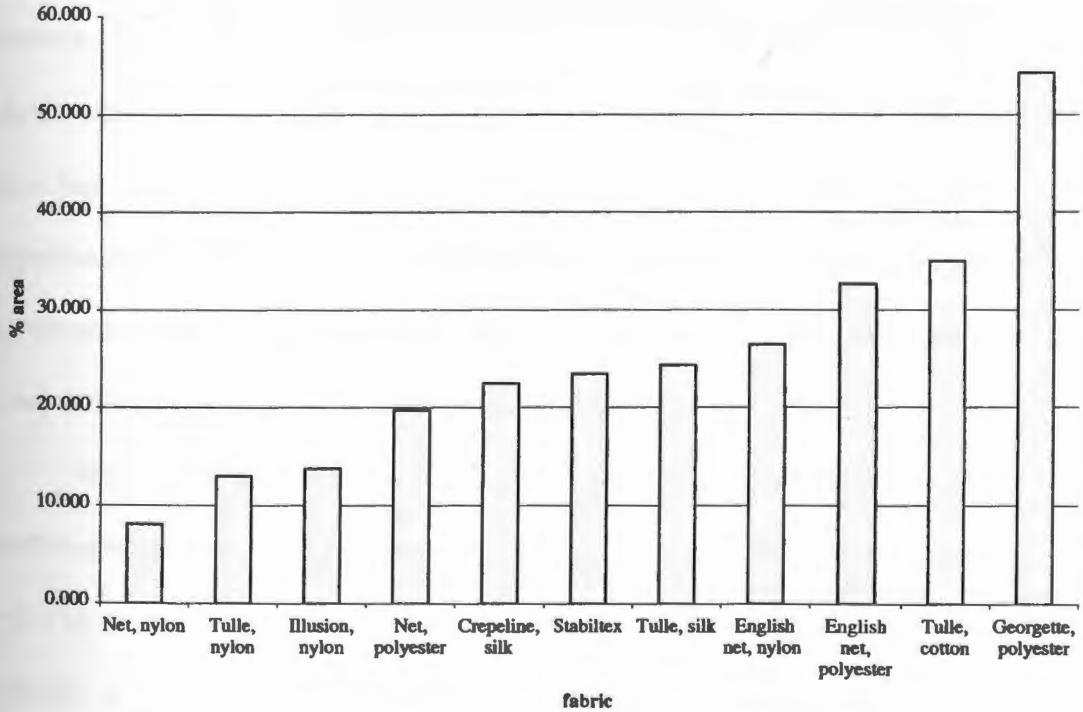

Figure 31. Cover factor of overlay fabrics

at 13.02% and 13.78%, also were very sheer. Silk crepeline, at 22.43%, and Stabiltex, at 23.42%, fell near the middle of the range for sheerness.

A one-way ANOVA comparing the means of all eleven fabrics indicated a significant difference between at least two fabrics ($p < 0.01$). Tukey HSD analysis of cover produced nine homogeneous subsets. See Table 8. It indicated that the four least sheer fabrics, those with highest cover, (the two English nets, cotton tulle, and polyester georgette) were significantly different from all other fabrics and from each other. The sheerest fabric, nylon net, also was significantly different from all other fabrics. The three mono-filament fabrics, nylon tulle, nylon illusion, and polyester net, clustered together and had very low cover. Nylon tulle and nylon illusion were significantly different from the other fabrics, but were not statistically different from each other. Polyester net was significantly different from all other fabrics. The mono-filament yarns in these fabrics enhance the sheerness of their knit structure and create fabrics with low cover. Except for nylon net, all the fabrics made from multi-filament yarns had higher cover than the mono-filament yarn fabrics. The means of silk crepeline and Stabiltex were not significantly different, and Stabiltex also was not significantly different from silk tulle. The staple fiber cotton fabric also had high cover and was significantly different from all other fabrics.

When cover was paired with the other variables using Spearman's correlation coefficients, cover correlated positively with thickness ($r=0.505$; $p=0.01$), weight ($r=0.825$; $p=0.01$), warp fabric count ($r=0.607$; $p=0.01$), and filling fabric count ($r=0.483$; $p=0.01$). Cover correlated negatively with static cling in the warp ($r=0.446$;

Table 8. Cover, Tukey's homogeneous Subsets (alpha = 0.05)

Group	Sig	Least	Nylon net	Nylon tulle	Nylon illusion	Polyester net	Silk crepeline	Stabiltex	Silk tulle	Polyester English net	Nylon English net	Cotton tulle	Polyester georgette	Most
1	1.000		—											
2	0.795			—	—									
3	1.000					—								
4	0.494						—	—						
5	0.566							—	—					
6	1.000									—				
7	1.000										—			
8	1.000											—		
9	1.000												—	
Fiber			nylon	nylon	nylon	polyester	silk	polyester	silk	polyester	nylon	cotton	polyester	
Fabric structure			raschel	tricot	tricot	tricot	woven	woven	raschel	raschel	raschel	raschel	woven	
Yarn			multi	mono	mono	mono	multi	multi	multi	multi	multi	staple	multi	

p=0.01) and filling (r=0.438; p=0.01) directions and with the amount of fiber left on the overlay fabric after abrasion (r=0.404; p=0.05).

Positive correlations between cover with thickness and cover with weight are also an indication that thicker, heavier fabrics are likely to be less transparent than thinner, lighter fabrics. The negative correlation between cover and electrostatic cling corroborates the correlations seen between fabric count and cling: the high cover, high fabric count wovens have lower cling times than the loosely knit, low cover, low hex count knitted nets.

Cover also can be used as an indicator of how much protection an overlay fabric offers from ultraviolet radiation and airborne particulate soils. The more open sheer fabrics with greater spaces between yarns allow light and particulate matter to affect the historic textile more than less sheer fabrics with higher cover.

Gloss

The Samba Advanced Vision System at Bossa Nova Tech, in Venice, California measured gloss. Stabiltex, made of the finest multi-filament yarn, was the glossiest fabric by a large margin at 26.43%. See Figure 32. Silk crepeline, another woven fabric, was next most glossy at 15.21%. This finding reflects the opinions of conservators such as Blum and colleagues that Stabiltex and silk crepeline give objects a sheen (Blum, et al. 2000). The two English nets, nylon net and polyester georgette, were clustered between 11 and 12%, while silk tulle, nylon tulle, polyester net, and nylon illusion clustered between 7.5 and 8.5%. Cotton tulle was the

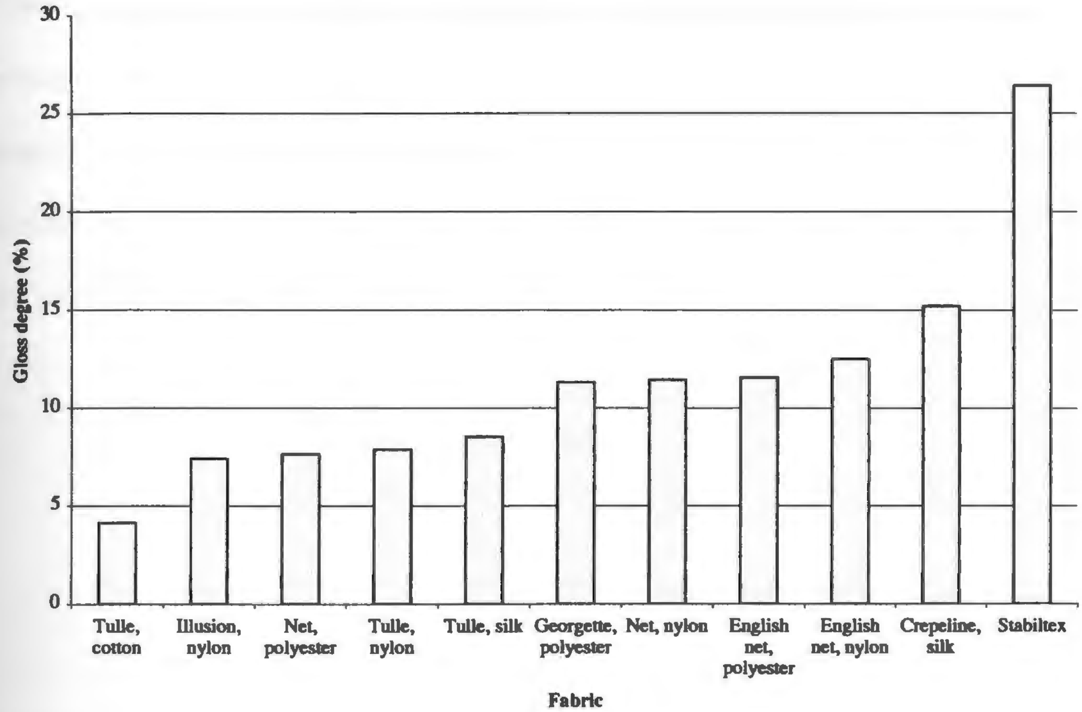

Figure 32. Gloss degree of overlay fabrics

least glossy at 4.13%. The only synthetic fiber fabric made of yarn without added delustrant, nylon net, was not the most glossy of the fabrics.

The fabrics made of delustered yarns ranged from the most glossy to the second least glossy, so delustrant in the yarn is not the only factor in controlling fabric gloss. This research did not quantify the amount of delustrant in the yarns. The three fabrics made of mono-filament yarn were the least glossy of the synthetic fiber fabrics.

Yarn twist in multi-filament yarns is important in determining the amount of gloss according to Kim and Shin (2004). They noted that as twist in multi-filament yarns increases, the luster unit size diminishes, which results in a macro-level gloss decrease. Stabiltex, the glossiest fabric, was woven of large diameter filaments (44 μ) that were only slightly twisted, producing large size luster units and high gloss which is consistent with Kim and Shin's research. Yarn twist was not quantified in this research because of the difficulty of unraveling a piece from the knitted nets long enough to evaluate. Testing the yarns prior to net manufacture for yarn twist and gloss degree could provide that data. Statistical analysis was not done on degree of gloss measurements because the data from Bossa Nova Tech was presented as single points for each fabric and multiple trial data were not available.

Mechanical Properties of Fabrics

Abrasiveness

The measure/count capability of digital image analysis software was used to quantify the effects of the abrasive action of sheer overlay fabrics using the ABD Materials Evaluator. Figures 33 and 34 show examples of the red cotton flannel fiber, fiber fragments, and fiber clumps visible on the overlay fabrics post-abrasion. The software calculated the area of red cotton fiber deposited on the sheer overlay fabrics by abrasion. These data are indicators of the abrasiveness of the fabrics tested.

Table 9 shows the area of cotton flannel fiber on the sheer overlays after abrasion. Nylon net loosened and transferred the most fiber from the cotton flannel fabric. The three tulle fabrics had the next three highest amounts of fiber transferred to their surface after abrasion. Polyester georgette was the least abrasive fabric,

Figure 33. Nylon net post-abrasion

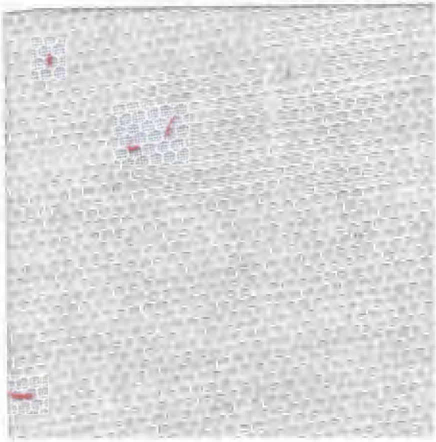

Figure 34. Silk tulle post-abrasion

Table 9. Abrasiveness with fabric characteristics

[illegible]bric	Area (mm^2)	Fabric structure	Yarn structure	Fiber
Georgette, polyester	0.0027	woven	multi	polyester
English net, polyester	0.1082	raschel	multi	polyester
Crepeline, silk	0.2763	woven	multi	silk
Stabiltex	0.3069	woven	multi	polyester
Illusion, nylon	0.6224	tricot	mono	nylon
Net, polyester	0.6725	raschel	mono	polyester
English net, nylon	0.7611	raschel	multi	nylon
Tulle, nylon	1.0378	tricot	mono	nylon
Tulle, silk	1.2135	raschel	multi	silk
Tulle, cotton	1.4933	raschel	staple	cotton
[illegible] nylon	1.7751	tricot	multi	nylon

followed by polyester English net, and then the other two wovens, silk crepeline and Stabiltex. Polyester georgette had almost no fiber present on the post-abrasion sample. Polyester English net had very little fiber on the post-abrasion samples. Figure 35 shows the same results graphically.

The fabrics made of natural fibers are spread throughout the range. The tulle made of cotton fiber is the second most abrasive fabric, and the silk tulle is near the

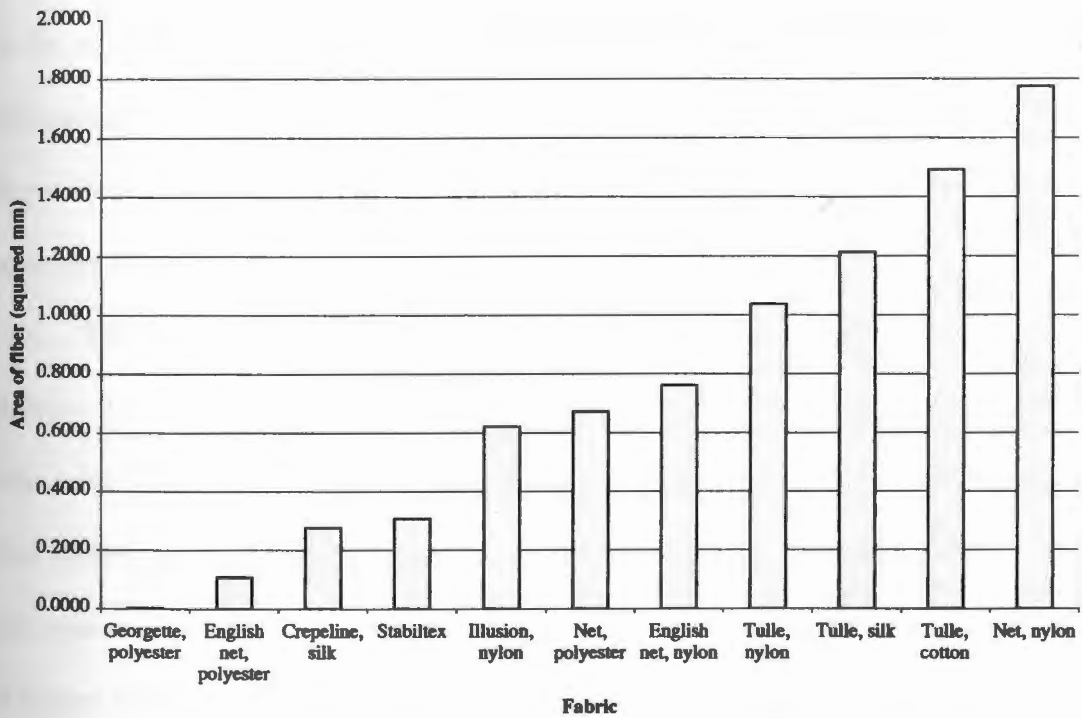

Figure 35. Area of fiber on overlay fabrics post-abrasion

top, while the silk crepeline is near the bottom of the rankings. The fabrics made of nylon yarn fall in the mid-range for amount of fiber; the polyester fabrics spread throughout the range. While the woven fabrics all are at the lowest end of the range, the tricot and raschel knits are spread along the range. The fabrics made of multi-filament yarns also spread throughout the range, as are those made of mono-filament yarns. The fabrics did not group together based on the shape of the interstices, hexagonal or diamond.

A one-way ANOVA showed a significant difference between at least two fabrics for the area of fiber deposited by abrasion ($p<0.01$). Tukey's HSD method, based on mean abrasiveness, produced two statistically significantly different groups (not necessarily mutually exclusive) for abrasiveness as measured by area of fiber left on the overlay fabric. See Table 10. These groups were highly overlapping homogeneous subsets with high degrees of separation at $p=0.067$ and $p=0.064$ respectively. The analysis showed that nylon net was significantly more abrasive than polyester georgette and polyester English net.

The digital imaging software also produced data by counting the number of objects. The software could not distinguish objects by size; therefore, large clumps of fiber, small individual fibers, and fiber fragments were each counted as one object. This technique needs modification to account for object size. Statistical analysis was not done on these data, but they are presented graphically along with the area of fiber in Figure 36. This graph shows that the three woven fabrics and polyester English net had the lowest number of fibers, fiber fragments, and fiber clumps present after abrasion. The fabrics with the highest object counts after abrasion were all knits. Nylon net had the highest count, again indicating that it is the most abrasive. The one fabric made from a staple fiber, the cotton tulle, was at the high end of the range because the protruding ends of the cotton fiber in the tulle could easily entangle the

Table 10. Abrasiveness, Tukey's homogeneous subsets (alpha = 0.05)

Group	Sig	Least	Polyester georgette	Polyester English net	Silk crepeline	Stabiltex	Nylon illusion	Polyester net	Nylon English net	Nylon tulle	Silk tulle	Cotton tulle	Nylon net	Most
1	0.067													
2	0.064													
Fiber			polyester	polyester	silk	polyester	nylon	polyester	nylon	nylon	silk	cotton	nylon	
Fabric structure			woven	raschel	woven	woven	tricot	tricot	raschel	tricot	raschel	raschel	raschel	
Yarn			multi	multi	multi	multi	mono	mono	multi	mono	multi	staple	multi	

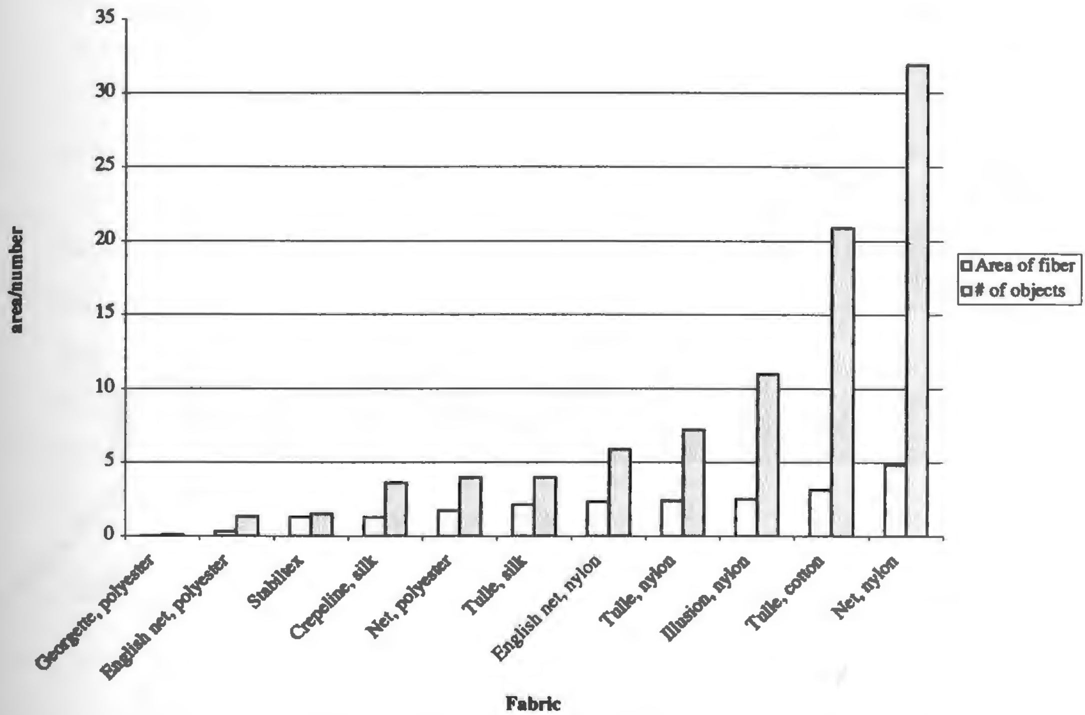

Figure 36. Area of fiber on overlay fabrics post-abrasion with number of fibers post-abrasion

cotton fibers from the flannel fabric and loosen them from yarns and fabric. According to Schindler (2004), fabric finishes applied to enhance the hand of the fabric also may improve the abrasion resistance, elasticity, and flexibility of the fabric. They also may change the abrasiveness of the fabric and could be a factor in these results.

When comparing abrasiveness to other fabric properties, neither surface roughness nor coefficient of friction ranks the fabrics similarly to the abrasiveness results. See Figures 37 and 38. Fabrics with high warp coefficients of friction spread across the range for abrasiveness. The least abrasive fabric, polyester georgette, and

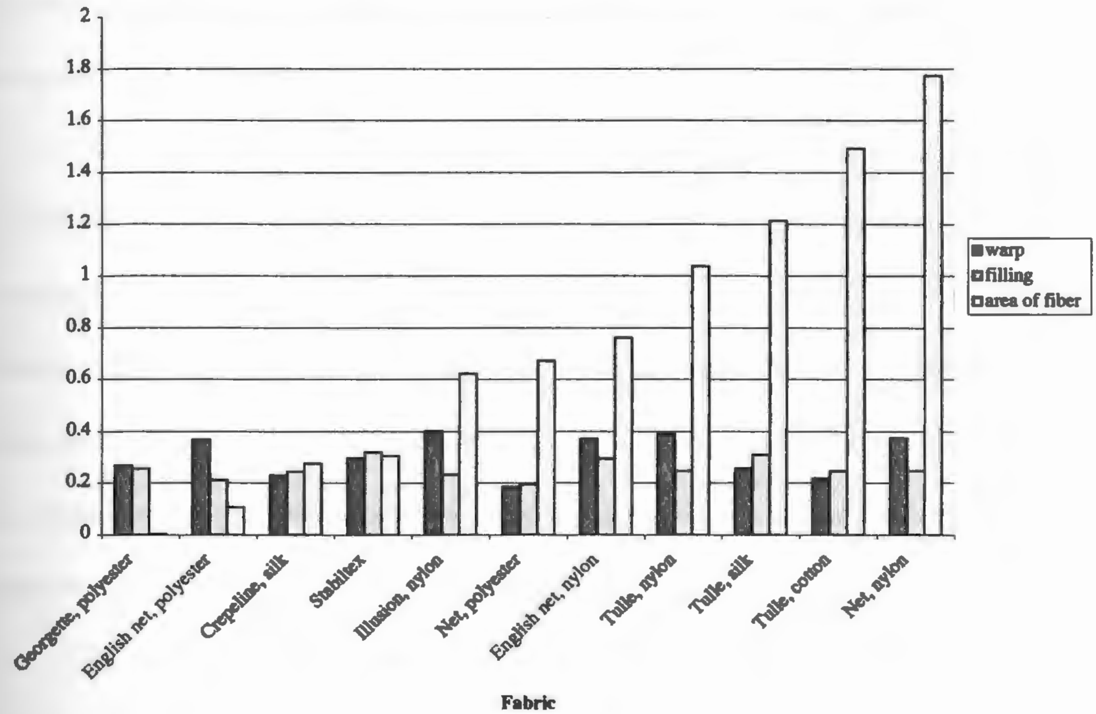

Figure 37. Area of fiber post-abrasion with coefficient of friction

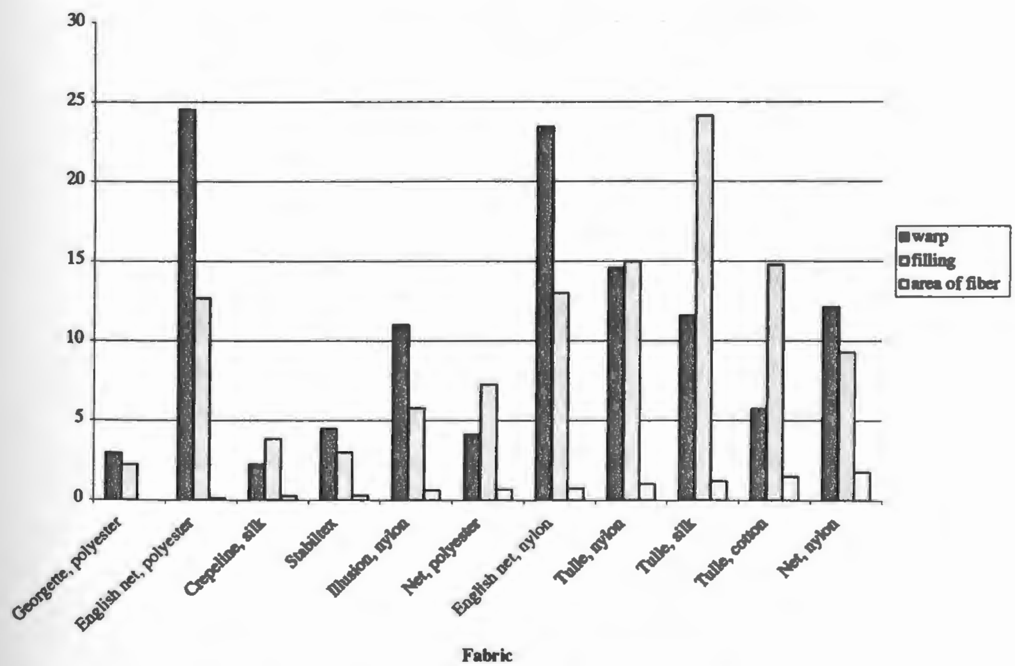

Figure 38. Area of fiber post-abrasion with surface roughness

the most abrasive fabric, nylon net, both had moderate friction rankings in both the warp and filling directions

The fabric with the highest warp surface roughness, polyester English net, was one of the lowest for abrasiveness. The other English net, nylon English net, ranked very high for warp roughness and near the middle for abrasiveness. The most abrasive fabric, nylon net, had moderate roughness in both the warp and filling directions. The least abrasive fabric did have the lowest filling roughness, and the three fabrics with the highest ranking filling roughness were the three most abrasive, but the most abrasive, nylon net, was only the third most rough.

The Spearman's rho correlations as shown in Table 11 support the difference in rankings seen in Figures 37 and 38. No significant correlations

Table 11. Abrasiveness correlation coefficients

Property	Coefficient	Sig
Cover	-0.404	0.020**
Fabric count, warp	-0.456	0.000*
Fabric count, filling	-0.459	0.000*
Friction, warp	0.117	0.516ns
Friction, filling	0.002	0.993ns
Growth, warp	0.685	0.000*
Growth, filling	0.473	0.026**
Roughness, warp	0.181	0.313ns
Roughness, filling	0.391	0.024**
Static cling, warp	0.371	0.330**
Static cling, filling	0.329	0.610ns
Stretch, warp	0.634	0.002*
Stretch, filling	0.409	0.590ns
Thickness	0.107	0.293ns
Weight	-0.260	0.089ns

* significant at $\alpha \leq 0.01$
** significant at $\alpha \leq 0.05$
ns not significant

between fabric friction and abrasiveness were found. In addition, no correlation existed between warp surface roughness and abrasiveness and only a slight correlation between filling surface roughness and abrasiveness.

Pairing abrasiveness data with other variables, Spearman's rho indicates a positive correlation between area of fiber with warp stretch, warp growth, and filling growth. Area of fiber correlated negatively with cover and fabric count in both directions, warp and filling. Abrasiveness was not significantly correlated with filling stretch, warp friction, filling friction, or warp roughness. The researcher expected that fabric friction and roughness would be highly correlated with abrasiveness. These results show that no significant linear relationship exists between fabric friction and abrasiveness, and surface roughness shows only a slight relationship in the filling direction.

The positive correlations with warp and filling growth indicate that factors that affect fabric growth, such as fabric structure, also may be variables of interest in abrasiveness results. Fabric weight and thickness were not significantly correlated with abrasiveness. These findings are consistent with Simpson's (1993) research in that fabric construction had more affect on the abrasiveness of backing fabrics than did weight and thickness.

Cover and fabric count both correlate negatively with abrasiveness. Cover and fabric count correlate positively with each other. The woven fabrics in the study had high fabric counts and high cover but low abrasiveness. The knitted nets had lower cover and lower fabric count with higher abrasiveness results. Determining fabric count is easily done, and cover can be estimated by eye without a detailed measurement, so these two properties may be useful as a quick estimate of abrasiveness.

The correlation with stretch and growth is similarly easy to use when choosing an overlay. Conservators can estimate the amount of stretch in an overlay fabric without the need for expensive testing equipment. Based on data in this research, the least abrasive overlay fabric would be one with low stretch, high fabric count, and high cover cover. Unfortunately, high fabric count and high cover mean that a fabric is less transparent. Cover, fabric count, and stretch may be used as predictor properties for abrasiveness to assist conservators in choosing overlay fabrics that will not be abrasive.

Coefficient of Friction

The Kawabata Evaluation System measured the coefficient of friction. Data were reported as means in both warp and weft directions and as a grand average, which combined data from both directions into one value. One-way ANOVA was performed on the overall mean friction coefficients of the eleven fabrics to determine the existence of significant differences between at least two fabrics. The ANOVA proved significant differences existed between at least two fabrics ($p \leq 0.01$) in the friction of the fabrics, therefore Tukey homogeneous subset analysis was done. An ANOVA could not be performed on the grand average data because the KES produces only one value per fabric, and replicated values were not available for analysis.

Polyester net had the lowest coefficient of friction in the warp direction. See Table 12. Cotton tulle and silk crepeline also had friction coefficients at the low end

Table 12. Warp coefficient of friction and fabric characteristics

Fabric	Warp	Fiber	Fabric structure	Yarn structure
Net, polyester	0.1850	polyester	tricot	mono
Tulle, cotton	0.2186	cotton	raschel	staple
Crepeline, silk	0.2306	silk	woven	multi
Tulle, silk	0.2574	silk	raschel	multi
Georgette, polyester	0.2689	polyester	woven	multi
Stabiltex	0.2972	polyester	woven	multi
English net, polyester	0.3687	polyester	raschel	multi
English net, nylon	0.3709	nylon	raschel	multi
Net, nylon	0.3743	nylon	raschel	multi
Tulle, nylon	0.3929	nylon	tricot	mono
Illusion, nylon	0.4012	nylon	tricot	mono

of the range in the warp direction. This indicates that more force would be required to move these fabrics across another surface than fabrics with higher coefficients of friction. The four nylon fabrics had the highest coefficients of friction in the warp direction. The top five fabrics are all knits. Nylon illusion had the highest friction, then nylon tulle, nylon net, and nylon English net was fourth. This indicates that these fabrics would slide in the warp direction more easily across other surfaces, including textiles, than the other fabrics. The three woven fabrics and those made of natural fibers were in the bottom half of the warp friction range. This indicates that these fabrics would slide, in the warp direction, less easily across other surfaces, including textiles, than the other fabrics. The fabrics made of mono-filament yarn were at opposite ends of the range; the polyester fabrics clustered mid-range, except for the polyester net.

Polyester net had the lowest coefficients of friction in the filling direction as it did in the warp direction. See Table 13. Polyester Stabiltex and silk tulle had the

Table 13. Filling coefficient of friction and fabric characteristics

Fabric	Filling	Fiber	Fabric structure	Yarn structure
Net, polyester	0.1954	polyester	tricot	mono
English net, polyester	0.2116	polyester	raschel	multi
Illusion, nylon	0.2336	nylon	tricot	mono
Crepeline, silk	0.2455	silk	woven	multi
Tulle, cotton	0.2469	cotton	raschel	staple
Net, nylon	0.2481	nylon	raschel	multi
Tulle, nylon	0.2524	nylon	tricot	mono
Georgette, polyester	0.2574	polyester	woven	multi
English net, nylon	0.2966	nylon	raschel	multi
Tulle, silk	0.3106	silk	raschel	multi
Stabiltex	0.3199	polyester	woven	multi

highest filling friction coefficients. Three of the four nylon fabrics still had high friction in the filling direction, but the order within those four fabrics was reversed: English net had the highest, then nylon tulle, and nylon net had the lowest. Nylon tulle had a low ranking for filling friction. Neither fiber content nor fabric structure were grouped in the filling direction as they were in the warp direction.

The differences between rankings reported in Tables 12 and 13 probably are determined by the structures of the knits. Fabric finishes also can affect the measurement of the coefficient of friction, but because information about finishes on the tested fabrics is incomplete, the impact of the finishes cannot be analyzed. These coefficient of friction results are graphically displayed in Figure 39.

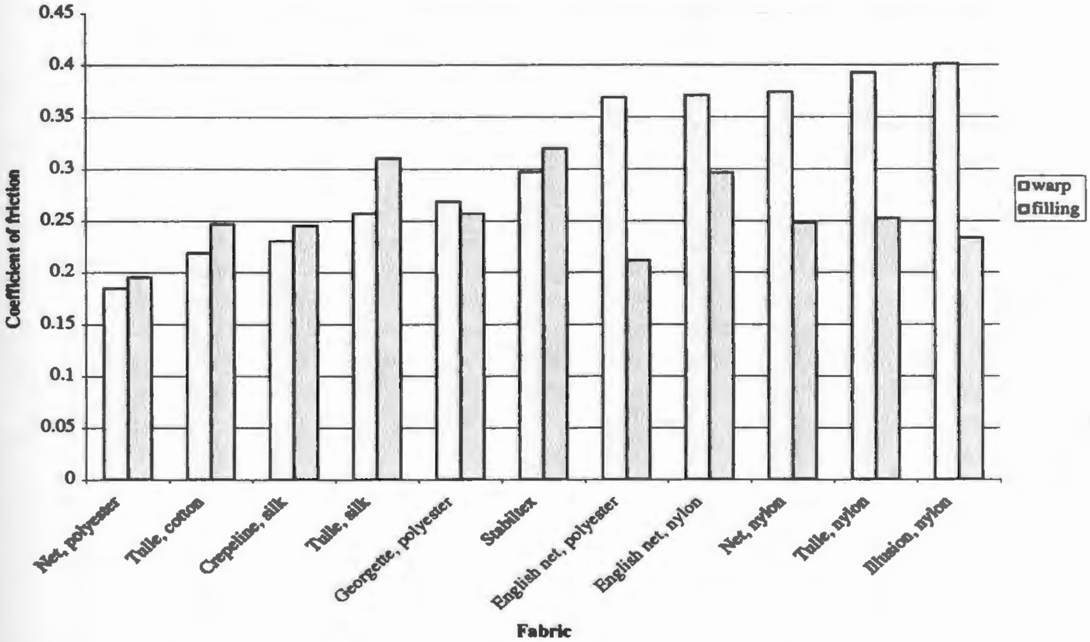

Figure 39. Coefficient of friction of overlay fabrics

Tukey's HSD method produced four statistically significantly different subsets from the eleven fabrics for friction in the warp direction, and five subsets in the filling direction. See Tables 14 and 15. Tukey HSD method indicated that the four nylon fabrics with the highest coefficient of friction, in the warp direction plus the polyester English net were significantly different from the other fabrics, but not significantly different from each other. Polyester net, cotton tulle, and silk crepeline had the lowest coefficient of friction in the warp direction and were not significantly different from each other. The polyester net also had the lowest coefficient of friction in the filling direction. It had a different tricot knit structure than all the other fabrics, as shown in Figure 18 and is made of a mono-filament yarn. The other mono-filament yarn tricot-knit fabrics had different results. Nylon illusion had a high coefficient of friction in the warp direction and a low one in the filling direction, while nylon tulle had a high

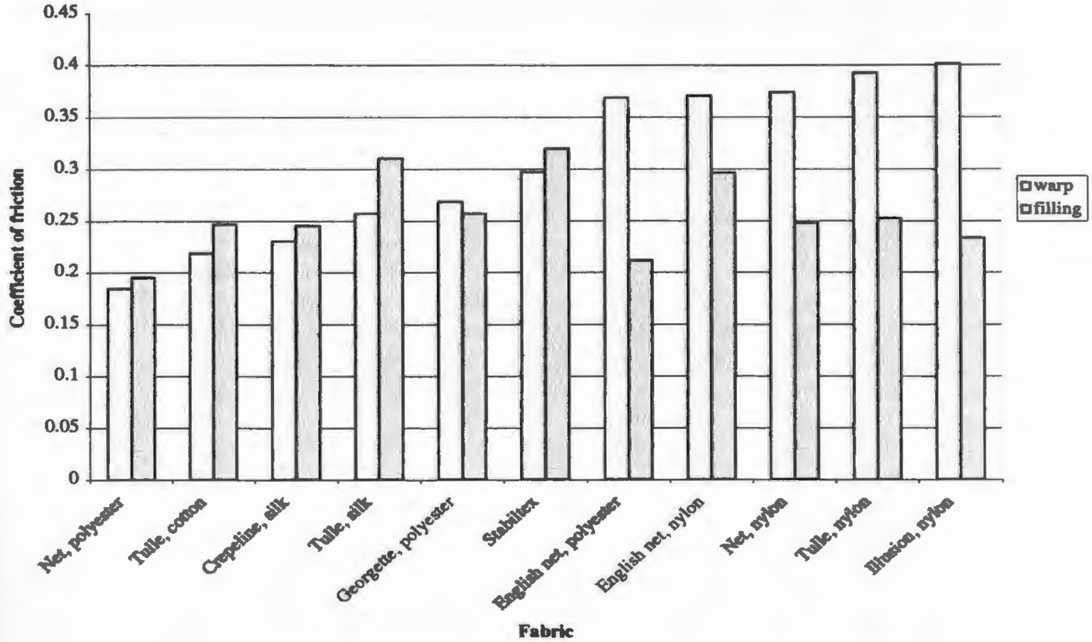

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Table 14. Coefficient of friction, warp, Tukey's homogeneous subsets (alpha = 0.05)

Group	Sig	Lowest	Polyester net	Cotton tulle	Silk crepeline	Silk tulle	Polyester georgette	Stabiltex	Polyester English net	nylon English net	Nylon net	Nylon tulle	Nylon illusion	Highest
1	0.454		—	—	—									
2	0.325			—	—	—	—							
3	0.073				—	—	—	—						
4	0.843								—	—	—	—	—	
Fiber			polyester	cotton	silk	silk	polyester	polyester	polyester	nylon	nylon	nylon	nylon	
Fabric structure			tricot	raschel	woven	raschel	woven	woven	raschel	raschel	raschel	tricot	tricot	
Yarn			mono	staple	multi	multi	multi	multi	multi	multi	multi	mono	mono	

Table 15. Coefficient of friction, filling, Tukey's HSD homogeneous subsets (alpha =0.05)

Group	Sig	Lowest	Polyester net	Polyester English net	Nylon illusion	Silk Crepeline	Cotton tulle	Nylon net	Nylon tulle	Polyester georgette	Nylon English net	Silk tulle	Stabiltex	Highest
1	0.077		—	—	—	—	—	—	—					
2	0.179			—	—	—	—	—	—	—				
3	0.094					—	—	—	—	—	—			
4	0.073									—	—	—		
5	0.910										—	—	—	
Fiber			polyester	polyester	nylon	silk	cotton	nylon	nylon	polyester	nylon	silk	polyester	
Fabric structure			tricot	raschel	tricot	woven	raschel	raschel	tricot	woven	raschel	raschel	woven	
Yarn			mono	multi	mono	multi	staple	multi	mono	multi	multi	multi	multi	

coefficient in both directions. Stabiltex, silk tulle, and nylon English net had the highest coefficients of friction in the filling direction. By Tukey HSD method, these three fabrics are not significantly different from each other.

Fiber content does not show up as a reason for grouping fabric friction in the filling direction as it does for the nylon fabrics in the warp direction. The two silk fabrics also show differences between warp and filling friction results. Silk crepeline and silk tulle both rank at the low end of the friction scale in the warp direction, but in the filling direction, silk tulle ranks at the high end of the scale, and silk crepeline ranks below the mid-point; and they are in significantly different subsets. Fabric structure does not follow any clear pattern in the Tukey subsets for friction in either the filling direction, but does in the warp direction.

The KES grand average for each fabric that combines the data from the warp and filling directions is in Figure 40. The four nylon nets continue to be at the high end of the range for overall friction, and the cotton tulle is near the low end. Collier and Epps (1999) reported that nylon fiber has a low coefficient of friction, yet in the warp direction in this test they are high possibly because fabric structure is the major contributor.

A higher coefficient of friction means that more force is required for these fabrics to slide across another surface. In conservation, materials sometimes are chosen because their surface has a higher friction and is able to grab or hold onto another fabric. This is important when choosing a support fabric for a textile displayed on a slanting mount board with little or no stitching to hold it in place. Overlays do not need to support a fabric the way a backing fabric does, but a fabric

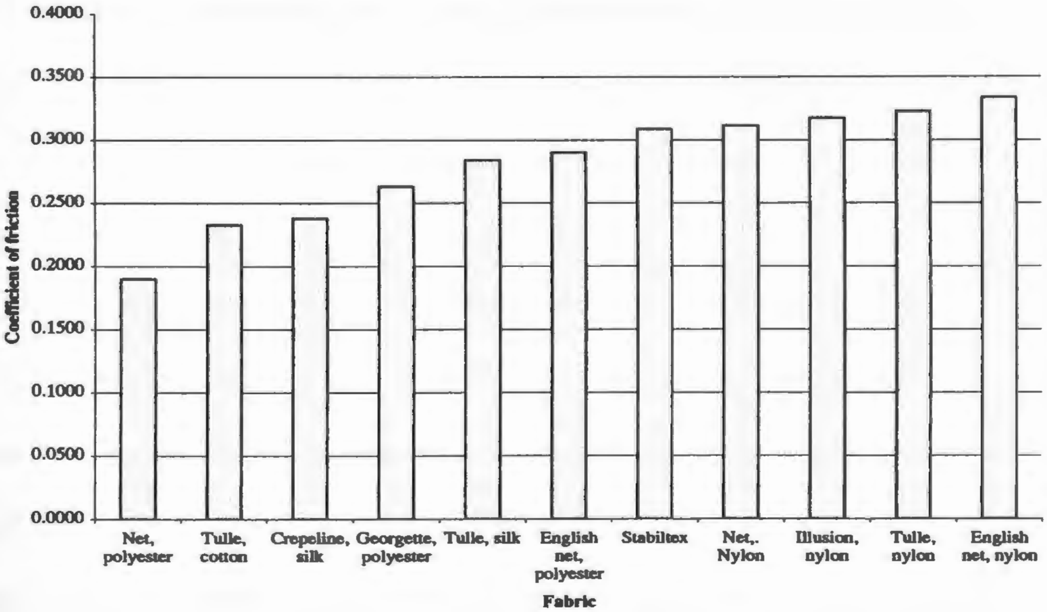

Figure 40. Coefficient of friction, grand average

with higher friction might grab onto the fragile textile underneath and limit fabric-to-fabric movement. The coefficient of friction was different in the warp and filling directions for many of the fabrics tested. This may make a difference in deciding how to apply the overlay to the fragile textile.

Statistical correlation coefficients were calculated between coefficients of friction and selected variables from the data set using Spearman's rho method. Warp coefficient of friction was negatively correlated with fabric count in the warp direction ($r=-0.726$; $p=0.01$) and cover ($r=-374$; $p=0.01$). This means that fabrics with high cover and high fabric count had low friction. An example would be the cotton tulle, which has high cover because the staple fiber ends protrude from the yarns increasing the surface area of the fabric, the cover and the coefficient of friction. Warp friction was positively correlated with stretch ($r=0.587$; $p=0.01$) and growth ($r=0.590$; $p=0.01$)

in the filling direction, but not in the warp direction. Filling friction was not correlated with stretch or growth in the warp or filling directions.

Neither warp nor filling friction correlated with the abrasion data. Friction was not correlated with electrostatic cling data. Only warp friction was correlated with warp roughness ($r=0.631$; $p=0.01$); filling friction was not correlated with warp or filling roughness, and warp friction was not correlated with filling roughness. This is a surprising result, as one would expect that friction and roughness might be correlated, especially in light of Ajayi's (1992) research in which he found that "frictional properties of woven fabrics may be interpreted in relation to surface smoothness and texture" (p. 87). However, Ajayi's research centered on woven fabrics; knit fabrics may have different relationships between friction and surface characteristics.

Surface Roughness

The Kawabata Evaluation System also measured surface roughness in both warp and filling directions. See Figure 41. The two English nets had the highest

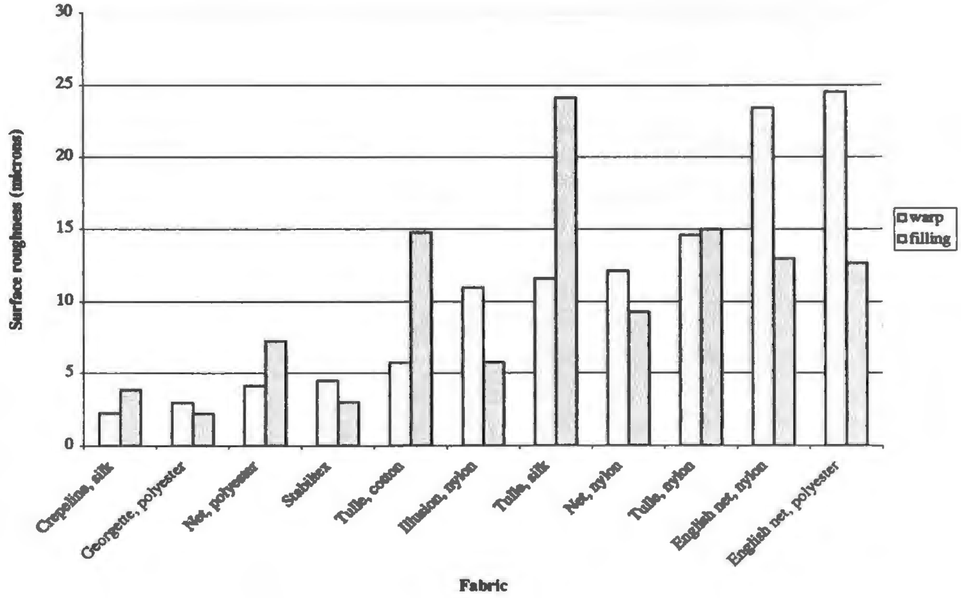

Figure 41. Surface roughness of overlay fabrics

surface roughness in the warp direction. The three wovens, plus polyester net, had the lowest roughness in the warp direction. Silk tulle had the highest roughness in the filling direction, with cotton tulle ranking second highest. The three wovens, plus nylon illusion were the four fabrics with the lowest filling roughness. In general, the woven fabrics had lower surface roughness than the knitted fabrics.

Examining fabric properties with respect to surface roughness showed that the two raschel knit English net fabrics had the highest surface roughness in the warp direction. See Table 16. The three woven fabrics had low roughness, but a tricot net (polyester net) also ranked among the lowest. Fiber content, yarn structure, and knit structure do not fall into any logical groupings within the warp surface roughness measures.

Table 16. Warp surface roughness and fabric characteristics

Fabric	Warp	Fiber	Fabric structure	Yarn structure
Crepeline, silk	2.26	silk	woven	multi
Georgette, polyester	2.95	polyester	woven	multi
Net, polyester	4.14	polyester	tricot	mono
Stabiltex	4.49	polyester	woven	multi
Tulle, cotton	5.75	cotton	raschel	staple
Illusion, nylon	10.98	nylon	tricot	mono
Tulle, silk	11.58	silk	raschel	multi
Net, nylon	12.14	nylon	raschel	multi
Tulle, nylon	14.59	nylon	tricot	mono
English net, nylon	23.42	nylon	raschel	multi
English net, polyester	24.52	polyester	raschel	multi

as measured in microns

Table 17. Filling surface roughness and fabric characteristics

Fabric	Filling	Fiber	Fabric structure	Yarn structure
Georgette, polyester	2.23	polyester	woven	multi
Stabiltex	3.01	polyester	woven	multi
Crepeline, silk	3.85	silk	woven	multi
Illusion, nylon	5.78	nylon	tricot	mono
Net, polyester	7.24	polyester	tricot	mono
Net, nylon	9.26	nylon	raschel	multi
English net, polyester	12.68	polyester	raschel	multi
English net, nylon	12.98	nylon	raschel	multi
Tulle, cotton	14.77	cotton	raschel	staple
Tulle, nylon	15.00	nylon	tricot	mono
Tulle, silk	24.14	silk	raschel	multi

as measured in microns

Within the filling surface roughness rankings, fabric structure clearly divides the fabrics into groups. All the raschel knit fabrics are above the median of the roughness scale in the filling direction. See Table 17. The three woven fabrics have the lowest surface roughness in the filling direction. Two of the tricot fabrics group just below the median of the range. The three tulle fabrics had the highest surface roughness in the filling direction. Fiber content and yarn structure do not form groups within the rankings.

The yarns in knitted nets cross each other at multiple angles. They also have greater variability in the size of the interstices than do the woven fabrics. These characteristics of fabric structure contribute to the higher roughness of the knits over the woven fabrics in both warp and filling directions.

One-way ANOVA on all eleven fabrics showed significant difference between at least two of the fabrics at ($p<0.01$). Tukey's HSD method produced five statistically significantly different subsets from the eleven fabrics for friction in the warp direction, and eight subsets in the filling direction. See Tables 18 and 19. The two English nets with the highest warp surface roughness are significantly different from all other fabrics but not from each other. Nylon illusion, silk tulle, and nylon net are near the median for warp roughness and fall into a homogeneous subset. The other subsets in the warp direction overlap and have a high degree of mean separation within their subsets.

In the filling direction, most of the subsets are distinct, and the groups have low degrees of mean separation within their subsets. The silk tulle is significantly different from all other fabrics including the other tulles with the highest surface

Table 18. Surface roughness, warp, Tukey's homogeneous subsets (alpha = 0.05)

Group	Sig	Lowest	Silk crepeline	Polyester georgette	Polyester net	Stabiltex	Cotton tulle	Nylon illusion	Silk tulle	Nylon net	Nylon tulle	Nylon English net	Polyester English net	Highest
1	0.132		—	—	—	—								
2	0.508				—	—	—							
3	0.863							—	—	—				
4	0.071									—	—			
5	0.896											—	—	
Fiber			silk	polyester	polyester	polyester	cotton	nylon	silk	nylon	nylon	nylon	polyester	
Fabric structure			woven	woven	tricot	woven	raschel	tricot	raschel	raschel	tricot	raschel	raschel	
Yarn			multi	multi	mono	multi	staple	mono	multi	multi	mono	multi	multi	

Table 19. Surface Roughness, filling, Tukey's HSD homogeneous subsets (alpha = 0.05)

Group	Sig	Lowest	Polyester georgette 3	Stabiltex 10	Silk crepeline 4	Nylon illusion 7	Polyester net 9	Nylon net 2	Polyester English net 6	Nylon English net 1	Cotton tulle 8	Nylon tulle 11	Silk tulle 5	highest
1	0.571		—	—										
2	0.473			—	—									
3	1.000					—								
4	1.000						—							
5	1.000							—						
6	0.999								—	—				
7	1.000										—	—		
8	1.000												—	
Fiber			polyester	polyester	silk	nylon	polyester	nylon	polyester	nylon	cotton	nylon	silk	
Fabric structure			woven	woven	woven	tricot	tricot	raschel	raschel	raschel	raschel	tricot	raschel	
Yarn			multi	multi	multi	mono	mono	multi	multi	multi	staple	mono	multi	

roughness. The second and third ranked cotton and nylon tulle are significantly different from all other fabrics, but not from each other. The two English nets form a subset just above the median. Nylon illusion, polyester net, and nylon net rank mid-range for roughness and are each significantly different from all other fabrics. The three wovens with the lowest roughness fall into two subsets and have high degrees of mean separation within their subsets.

The KES data produced a grand average, which combined the measures from both warp and filling directions and allowed a comparison of fabrics as a whole. See Figure 42. Statistical analysis was not done on this data because it was reported as a

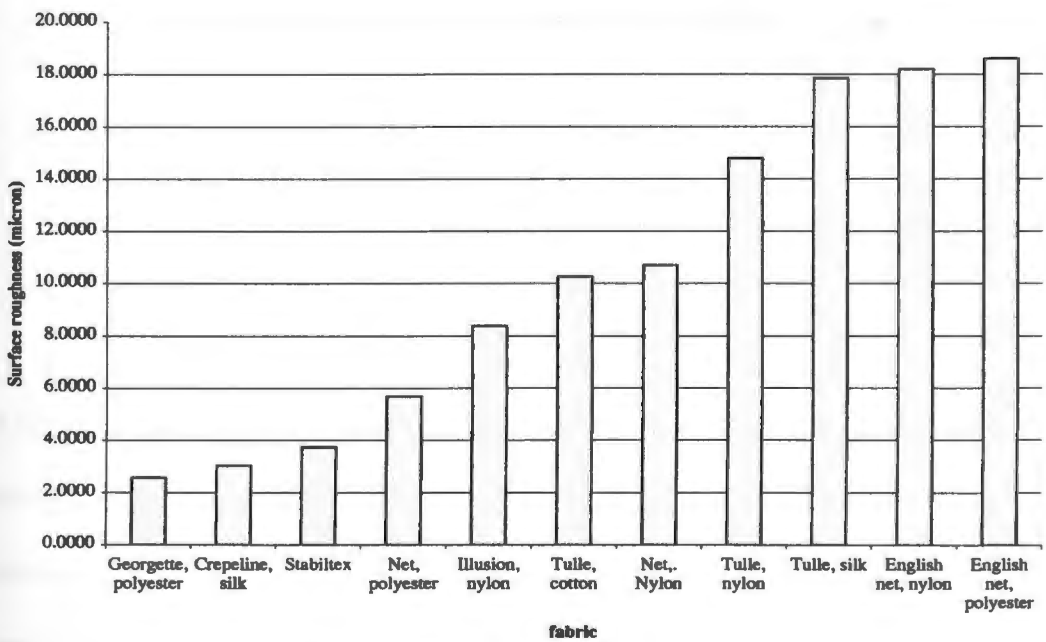

Figure 42. Surface roughness, grand average

single value and multiple trial data was not available. The two English nets had the highest overall surface roughness, while the three woven fabrics: georgette, crepeline and Stabiltex, had the lowest. Silk tulle also had high overall roughness.

Spearman's rho showed that both the warp and filling direction of surface roughness was negatively correlated with fabric count. See Table 20. This may be explained by fabric structure with the high count, low roughness wovens at one end of the scale and with the low count, high roughness knitted nets at the other end of the scale. Warp and filling roughness were positively correlated with electrostatic cling in both the warp and filling directions

Filling roughness was positively associated with warp stretch (r=0.540; p=0.01), filling stretch (r=0.573; p=0.01), warp growth (r=0.601; p=0.01),

Table 20. Surface roughness correlation coefficients

	Surface Roughness			
	Warp		Filling	
	Coefficient	Sig	Coefficient	Sig
Fabric count, warp	-0,756	0.000*	-0.453	0.008*
Fabric count, filling	-0.616	0.000*	-0.547	0.001*
Cling time, warp	0.473	0.005*	0.446	0.009*
Cling time, filling	0.446	0.009*	0.407	0.019*

* significant at $\alpha \leq 0.01$

and filling growth (r=0.654;p=0.01). The fabric structure of warp knits with yarn underlaps running in the filling direction may be affecting these variables. Warp roughness was not correlated with warp stretch or growth, but was positively correlated with filling stretch (r=0.857; p=0.01) and growth (r=0.826; p=0.01). Filling roughness was positively correlated with the area of fiber (r=0.391; p=0.05) left on the overlay fabrics after abrasion, but warp roughness was not significantly correlated with this variable. This research used orbital abrasion, which may be a confounding variable in this result. A repetition of the test using linear abrasion, while controlling for warp and weft directions of the overlay fabrics, is needed to provide additional data with which to explain these results.

Elongation

Results from elongation tests are in Table 21. The data were measured in millimeters but are expressed here as a percentage of total. The data set was incomplete because both samples of nylon net broke before the end of the test in the filling direction, and one sample of the nylon illusion broke in the warp direction. Nylon illusion had the greatest stretch in the warp direction almost doubling in length. It, along with the next four fabrics having the greatest amount of stretch in the warp direction, also had the greatest amount of growth in that direction. The illusion and the two others that rank high in stretch and growth are tricot knit fabrics made of mono-filament yarns.

Table 21. Percentage stretch and growth in overlay fabrics

	Stretch		Growth	
Fabric	Warp	Filling	Warp	Filling
Stabiltex	1.0	2.0	0.5	0.5
Crepeline, silk	1.0	3.0	1.0	1.0
Georgette, polyester	3.0	2.0	0.0	0.5
English net, polyester	13.0	104.0	5.0	30.5
English net, nylon	22.5	46.0	11.5	25.0
Net, nylon	24.0	78.5	8.0	broke
Tulle, cotton	29.5	8.5	21.0	6.0
Tulle, nylon	32.5	94.0	14.5	66.0
Net, polyester	42.0	35.0	27.0	23.0
Tulle, silk	51.5	34.5	41.0	26.5
Illusion, nylon	99.5	38.0	71.0	18.0

Warp knits generally have better stability in the warp versus filling direction, and the percent stretch and growth shown in Table 21 are higher for the filling direction than the warp direction. Nylon tulle had a higher stretch in the filling direction than all but one fabric, and all three tricot fabrics were above the median for filling stretch. The knitting technique of skipping underlaps necessary to create an open net increases the stretch of the fabric. An applied finish can affect the stretch and growth of a fabric. As expected, the three woven fabrics exhibited the most warp and filling stability with very little stretch ($\leq$ 3.0%) or growth ($\leq$1.0%).

One-way ANOVA was performed on the overall means of the eleven fabrics to determine the existence of significant differences between at least two fabrics. The ANOVA showed significant differences existed at the ($p<0.01$) in both the stretch and growth of the fabrics, therefore Tukey's Homogeneous Subset Analysis was done for both stretch and growth.

Tukey's HSD method produced eight statistically significantly different groups (not necessarily mutually exclusive) for stretch in the warp direction. See Table 22. Nylon illusion, silk tulle, and polyester net were each significantly different from all the other fabrics and exhibited the highest warp-wise stretch. Nylon English net also was significantly different from all the other fabrics but fell near the low end of the scale for warp-direction stretch. The three woven fabrics had the least stretch in the warp direction and were not significantly different from each other, but the set of three were significantly different from all of the knitted nets.

Tukey's HSD method produced four statistically significantly different groups (not necessarily mutually exclusive) for stretch in the filling direction. See Table 23. In the filling direction, only nylon net was significantly different from all of the other Fabrics, and it was at the high end of the range. The wovens had the least stretch in the filling direction because the plain weave fabric structure gives them little stretch. Cotton tulle joined the three wovens in the lowest subset.

Analysis of growth data by Tukey's HSD method produced two statistically significantly different groups (not necessarily mutually exclusive) in the warp direction. See Table 24. The two homogeneous subsets showed some overlap, and the means of these large groups had a high degree of separation as evidenced by significance of p=0.055 and p=0.057, respectively. This indicated that there is little difference among all of the fabrics for warp-wise growth. This may be due to differences in the stability of the woven structures versus the warp knit constructions or to warp-wise stretch imposed on the fabrics in the finishing process, thus inhibiting warp-wise growth in end use applications. The lack of data on the finishes on the fabrics in this research makes analysis of the impact of finish inconclusive.

Tukey HSD analysis of growth in the filling direction produced five statistically significantly different groups (not necessarily mutually exclusive) in the filling direction. See Table 25. Nylon tulle with the highest amount of filling growth was statistically significantly different from all other fabrics. The subset with the lowest filling growth consisted of the three wovens and the cotton tulle. Fabric structure affected the results of the filling stretch and growth tests. The other three

Table 22. Stretch, warp, Tukey's homogeneous subsets (alpha = 0.05)

Group	Sig	Least	Silk crepeline	Stabiltex	Polyester georgette	Nylon English net	Polyester English net	Nylon net	Cotton tulle	Nylon tulle	Polyester net	Silk tulle	Nylon illusion	Most
1	0.993		—	—	—									
2	1.000					—								
3	0.999						—	—						
4	0.074							—	—					
5	0.753								—	—				
6	1.000										—			
7	1.000											—		
8	1.000												—	
Fiber			silk	polyester	polyester	nylon	polyester	nylon	cotton	nylon	polyester	silk	nylon	
Fabric structure			woven	woven	woven	raschel	raschel	raschel	raschel	tricot	tricot	raschel	tricot	
Yarn			multi	multi	multi	multi	multi	multi	staple	mono	mono	multi	mono	

Table 23. Stretch, filling, Tukey's homogeneous subsets (alpha = 0.05)

Group	Sig	Least	Stabiltex	Polyester georgette	Silk crepeline	Cotton tulle	Silk tulle	Polyester net	Nylon illusion	Polyester English net	Nylon net	Nylon tulle	Nylon English net	Most
1	0.579		—	—	—	—								
2	0.079						—	—	—	—				
3	1.000										—			
4	0.163											—	—	
Fiber			polyester	polyester	silk	cotton	silk	polyester	nylon	polyester	nylon	nylon	nylon	
Fabric structure			woven	woven	woven	raschel	raschel	tricot	tricot	raschel	raschel	tricot	raschel	
Yarn			multi	multi	multi	staple	multi	mono	mono	multi	multi	mono	multi	

Table 24. Growth, warp, Tukey's HSD homogeneous subsets (alpha = .05)

Group	Sig	Least	Stabiltex	Polyester georgette	Silk crepeline	Nylon English net	Nylon net	Polyester English net	Nylon tulle	Cotton tulle	Polyester net	Silk tulle	Nylon illusion*	Most
1	0.055													
2	0.057												*	
Fiber			polyester	polyester	silk	nylon	nylon	polyester	nylon	cotton	polyester	silk	nylon	
Fabric structure			woven	woven	woven	raschel	raschel	raschel	tricot	raschel	tricot	raschel	tricot	
Yarn			multi	multi	multi	multi	multi	multi	mono	staple	mono	multi	mono	

* fabric broke during testing so no data were available for analysis

Table 25. Growth, filling, Tukey's homogeneous subsets (alpha = .05)

Group	Sig	Least	Stabiltex	Polyester georgette	Silk crepeline	Cotton tulle	Nylon illusion	Polyester net	Polyester English net	Silk tulle	Nylon English net	Nylon tulle	Nylon net*	Most
1	0.681													
2	0.104													
3	0.312													
4	0.253													
5	0.237													
6	1.000												*	
Fiber			polyester	polyester	silk	cotton	nylon	polyester	polyester	silk	nylon	nylon	nylon	
Fabric structure			woven	woven	woven	raschel	tricot	tricot	raschel	raschel	raschel	tricot	raschel	
Yarn			multi	multi	multi	staple	mono	mono	multi	multi	multi	mono	multi	

* fabric broke during testing so no data were available for analysis

Tukey subsets in the filling direction had a high amount of overlap and high degree of mean separation within their subsets.

Data are not complete for nylon illusion in the warp direction, and nylon net in the filling direction, because the fabric broke under the force of the CRE tester near the end of the stretch cycle and growth could not be measured. This is important for conservators, because these two fabrics could not withstand a constant four-pound load for five minutes. The structural integrity of the nylon illusion and the nylon tulle was compromised and their value as overlays under stress is questionable.

See Figure 43 for graphical presentation of warp stretch and growth data. The three woven fabrics had very little warp stretch or growth. The English nets

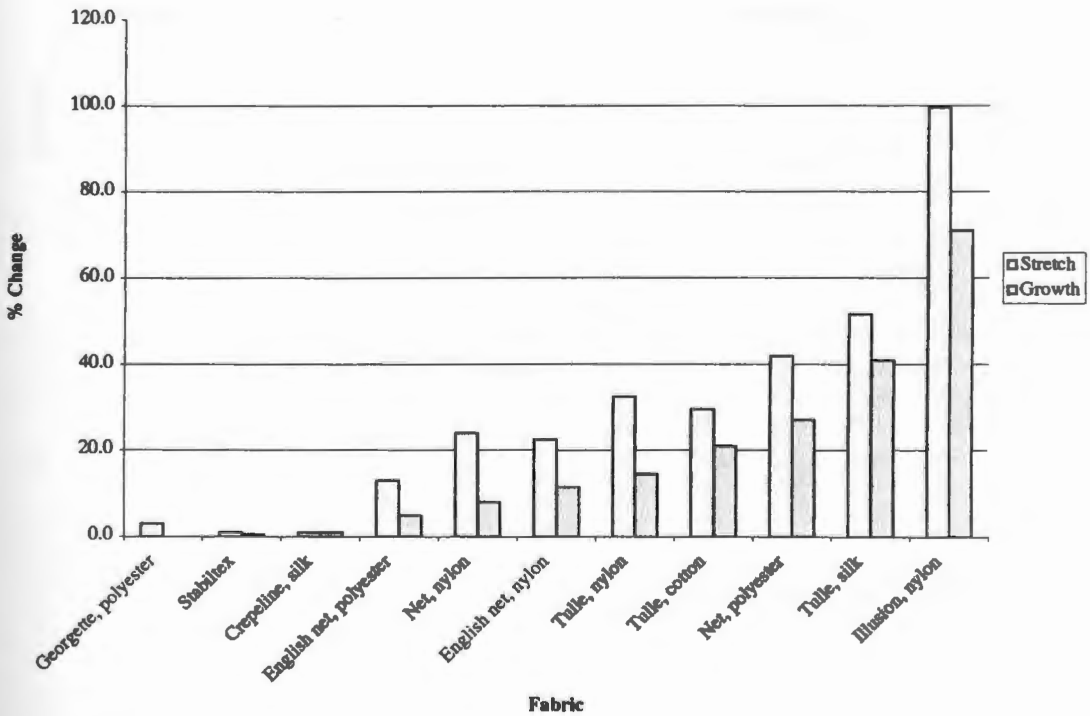

Figure 43. Percentage of warp stretch and growth of overlay fabrics

had low amounts of warp stretch and growth. Nylon illusion had a 100% stretch and 71% growth. Polyester net and silk tulle both had over 40% stretch.

Filling stretch and growth data are presented graphically in Figure 44. The three woven fabrics also had a low amount of filling stretch and growth. Cotton tulle had little filling stretch and growth. The two English nets had more filling stretch than warp stretch with the polyester English net having over 100% warp stretch. It showed excellent elastic recovery with only 31% growth. The nylon tulle stretched 94% in the filling direction and had 66% growth.

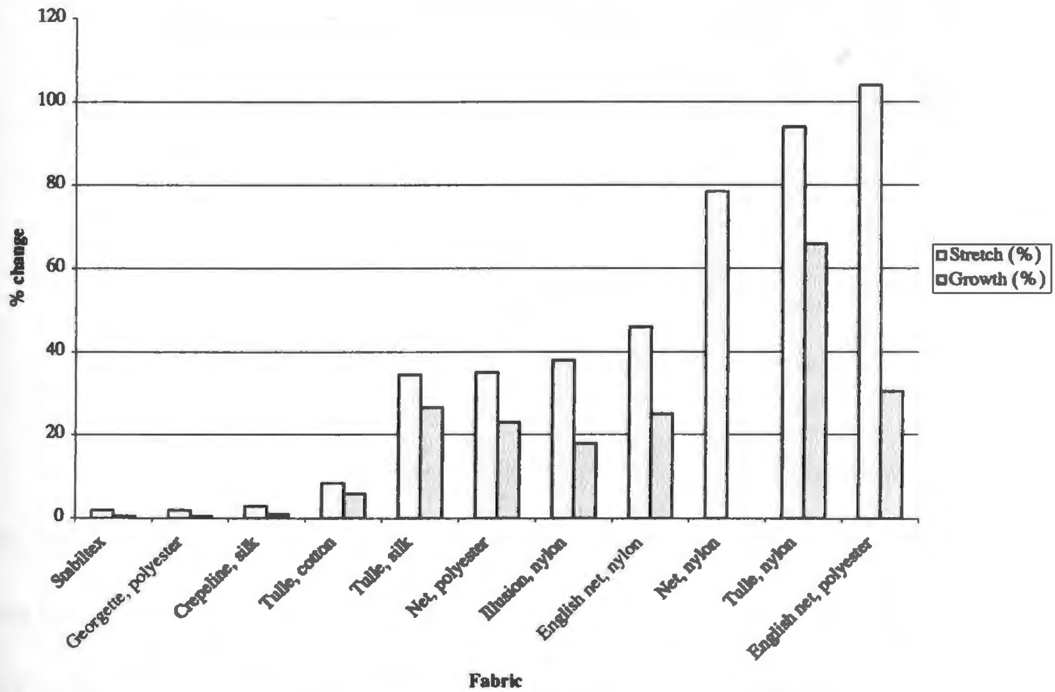

Figure 44. Percentage of filling stretch and growth of overlay fabrics

Figure 45 is a graphical presentation of warp and filling stretch data. These data show high variability in warp and filling stretch for the knitted fabrics, both tricot and raschel. For example, polyester English net has low warp stretch, but the highest amount of filling stretch. Fabric structure and the nature of warp knit nets may be the cause of the differences.

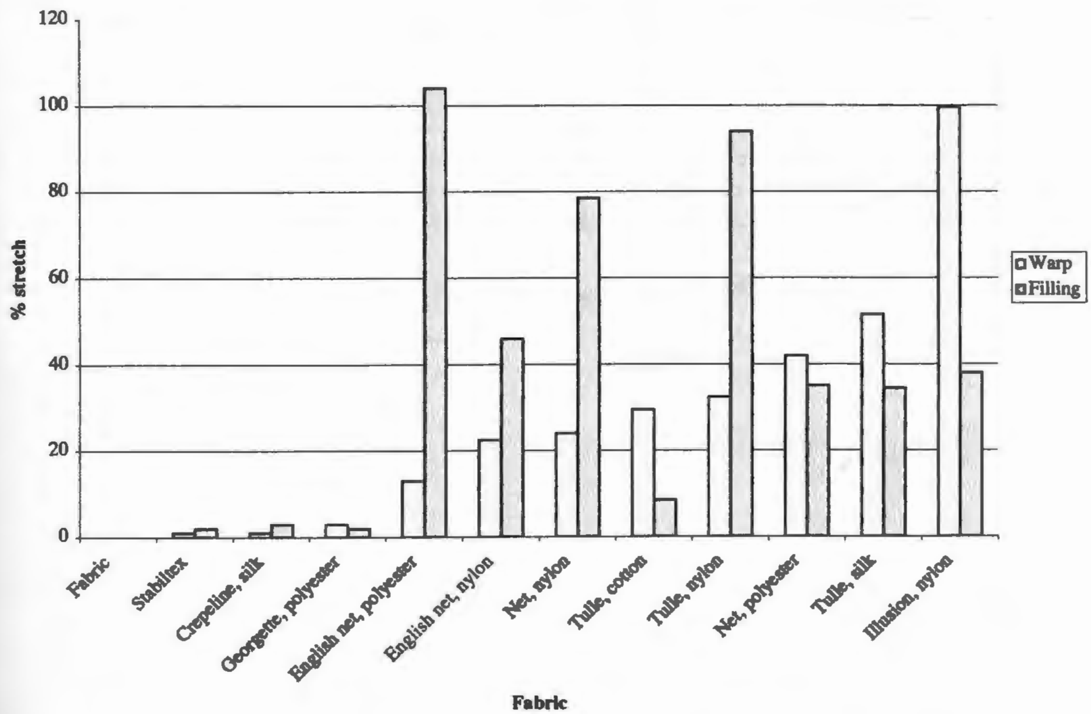

Figure 45. Percentage of stretch in warp and filling of overlay fabrics

Figure 46 shows the warp and filling growth data. As with the percent stretch data, cotton tulle, polyester net, silk tulle, and nylon illusion have more growth in the warp than filling directions while the other knits are the opposite. Many properties of the fibers, yarns, fabrics, and finishes contribute to these differences.

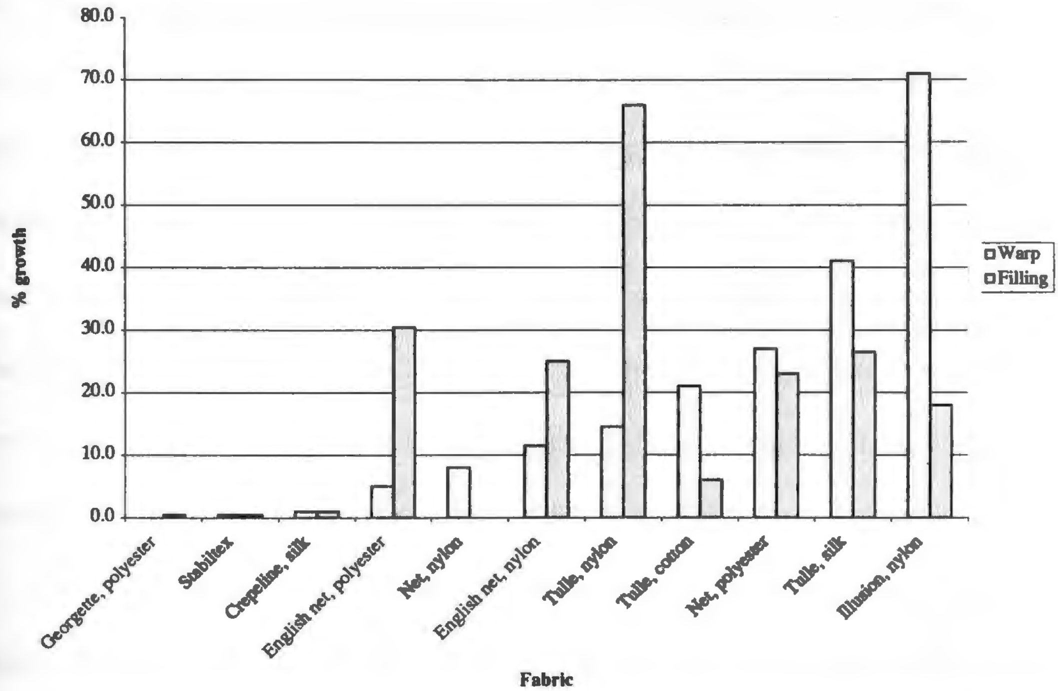

Figure 46. Percentage of growth in warp and filling of overlay fabrics

Table 26. Stretch and growth correlation coefficients

	Stretch				Growth			
	Warp		Filling		Warp		Filling	
Variable	Coefficient	sig	Coefficient	Sig	Coefficient	Sig	Coefficient	Sig
Fabric count, warp	-0.556	0.007*	-0.785	0.000*	-0.499	0.018**	-0.815	0.000*
Fabric count, filling	-0.594	0.004*	-0.654	0.001*	-0.579	0.005*	-0.741	0.000*
Abrasiveness, area	0.634	0.002*	0.409	0.059ns	0.685	0.000*	0.473	0.026**
Static cling, warp	0.624	0.002*	0.543	0.009*	0.601	0.003*	0.585	0.004*
Static cling, filling	0.635	0.002*	0.624	0.000*	0.725	0.002*	0.696	0.000*

* significant at $\alpha \leq 0.01$
** significant at $\alpha \leq 0.05$
ns not significant

Statistical correlation coefficients were calculated between selected pairs of data using Spearman's rho. See Table 26. Stretch in both warp and filling directions was correlated with growth in both warp and filling directions. As expected, warp stretch correlated positively with warp growth (r=0.945; p=0.01), and filling stretch correlated positively with filling growth (r=0.955; p=0.01). Warp stretch was not significantly correlated with filling stretch, nor was filling growth significantly correlated with warp growth. The positive correlations of abrasiveness with warp stretch and growth and filling growth, but not filling stretch, are cause for additional research. As mentioned in the abrasion section of this paper, tension during testing and orbital versus linear direction of abrasion may be additional variables to consider. These results also may be due to fabric structure. Because technical back and face were not controlled during abrasion, fabric face might be another confounding variable. Controlling all these variables could help to clarify these results.

Stretch and growth also positively correlated with electrostatic cling, and negatively with fabric count. The high count woven fabrics had the lowest amount of stretch and growth, while the low count, knitted nets had higher stretch and growth. This makes sense when considering fabric structure, as knitted nets are designed to have stretch.

Electrostatic Cling

Electrostatic cling data are presented in Figure 47. Four of the sheer overlays clung to the metal plate for the maximum time of 10 minutes in the filling direction. These were polyester net, silk tulle, nylon tulle, and nylon illusion. Three of these, excluding silk, are tricot fabrics made of mono-filament yarn. See Table 27. Both polyester net and silk tulle also showed maximum cling time in the warp direction. Nylon tulle (9.21 minutes) and nylon illusion (8.22 minutes) showed slightly less cling time in the warp direction. Two of the fabrics, polyester georgette and cotton tulle, did not cling at all in warp or filling directions. Stabiltex showed extremely short

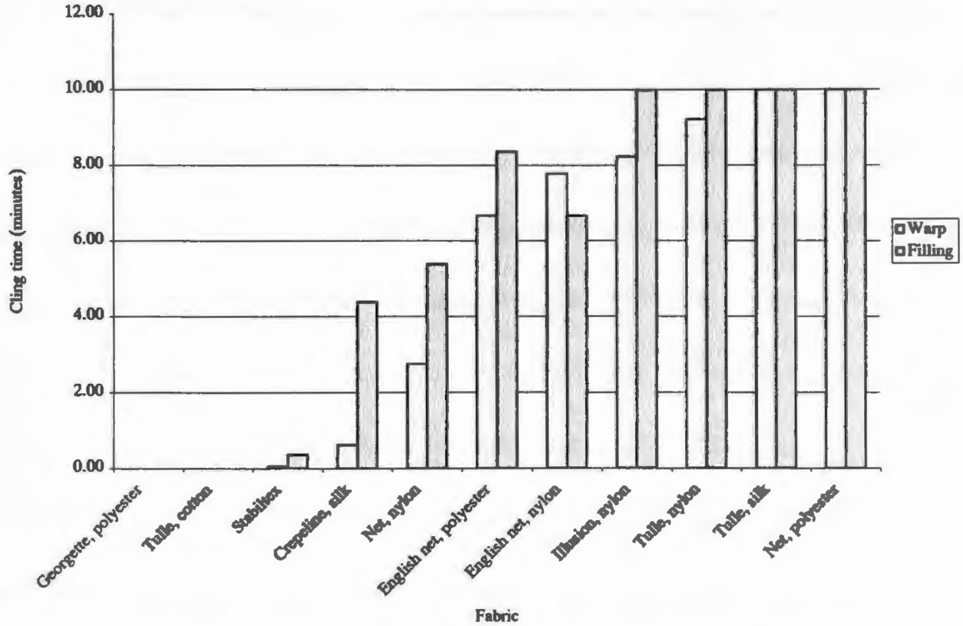

Figure 47. Electrostatic cling time of overlay fabrics

Table 27. Electrostatic cling time and fabric characteristics

Fabric	Warp	Filling	Fiber	Fabric structure	Yarn structure
Georgette, polyester	0.00	0.00	polyester	woven	multi
Tulle, cotton	0.00	0.00	cotton	raschel	staple
Stabiltex	0.06	0.37	polyester	woven	multi
Crepeline, silk	0.62	4.39	silk	woven	multi
Net, nylon	2.76	5.39	nylon	raschel	multi
English net, polyester	6.67	8.36	polyester	raschel	multi
English net, nylon	7.78	6.67	nylon	raschel	multi
Illusion, nylon	8.22	10.0	nylon	tricot	mono
Tulle, nylon	9.21	10.0	nylon	tricot	mono
Tulle, silk	10.00	10.0	silk	raschel	multi
Net, polyester	10.00	10.0	polyester	tricot	mono

measured in minutes

cling time in both directions (0.06 minutes warp, 0.37 minutes filling). Silk crepeline had minimal cling in the warp direction (0.62 minutes), but had moderate (4.39 minutes) cling in the filling direction. The two English nets and the nylon net fell in the middle of the range with cling times ranging from 2.76 minutes to 8.36 minutes.

The woven fabrics had very low charge build-up leading to static cling. Also, as expected, the cotton fabric had little cling. The three fabrics made of mono-filament yarns had the highest charge build up indicating that their high static cling also would make the fabrics attract charged airborne particles. These airborne particles could act as third-party abradants or chemically damaging pollutants when brought into proximity with the fragile textile under the overlay.

One-way ANOVA was performed on the overall means of the eleven fabrics to determine the existence of significant differences between at least two fabrics. The ANOVA proved significant differences existed at the ($p<0.01$) in the electrostatic cling of the fabrics, therefore Tukey Homogeneous subset analysis was done. See Tables 28 and 29. Tukey's HSD method produced four statistically significantly different groups (not necessarily mutually exclusive) in the warp direction and two groups in the filling direction. Tukey's HSD method did not show any of the fabrics to be significantly different from all of the other fabrics. The highest and lowest groups had low degrees of mean separation (0.911 and 0.773 respectively) within their subsets, meaning that the fabrics were very similar in their cling times. The two middle subsets had high degrees of mean separation (0.053 and 0.063) within their subsets.

Cling time in the warp direction was positively correlated with cling time in the filling direction ($r=0.725$; $p=0.01$), implying consistency of static cling within a fabric. See Table 30. When electrostatic cling was paired with the other variables

Table 28. Electrostatic cling, warp, Tukey's homogeneous subsets (alpha = 0.05)

Group	Sig	Least	Polyester georgette	Cotton tulle	Stabiltex	Silk crepeline	Nylon net	Polyester English net	Nylon English net	Nylon illusion	Nylon tulle	Silk tulle	Polyester net	Most
1	0.911		—	—	—	—	—							
2	0.053				—	—	—	—						
3	0.063						—	—	—	—	—			
4	0.773							—	—	—	—	—	—	
Fiber			polyester	cotton	polyester	silk	nylon	polyester	nylon	nylon	nylon	silk	polyester	
Fabric structure			woven	raschel	woven	woven	raschel	raschel	raschel	tricot	tricot	raschel	tricot	
Yarn			multi	staple	multi	multi	multi	multi	multi	mono	mono	multi	mono	

Table 29. Electrostatic cling, warp, Tukey's homogeneous subsets (alpha = 0.05)

Group	Sig	Least	Polyester georgette	Cotton gulle	Stabiltex	Silk crepeline	Nylon net	Nylon English net	Polyester English net	Silk tulle	Nylon illusion	Polyester net	Nylon tulle	Most
1	0.067		—	—	—	—	—	—						
2	0.190					—	—	—	—	—	—	—	—	
Fiber			polyester	cotton	polyester	silk	nylon	nylon	polyester	silk	nylon	polyester	nylon	
Fabric structure			woven	raschel	woven	woven	raschel	raschel	raschel	raschel	tricot	tricot	tricot	
Yarn			multi	staple	multi	multi	multi	multi	multi	multi	mono	mono	mono	

using Spearman's rho method, it was positively correlated with stretch, growth, roughness, and negatively correlated with fabric count and cover. The woven fabrics with high fabric counts and high cover had very low cling times. The cotton tulle fabric also had high cover, even though it was a knit and these factors, combined with the low conductivity of the fiber, made it fall in the same range as the wovens. The knitted nets with lower fabric counts and lower cover had higher cling times. Yarn and fabric structure, and fabric finish are the major variables affecting these results.

Table 30. Electrostatic cling correlation coefficients

	Electrostatic cling time			
	Warp		Filling	
Variable	Coefficient	Sig	Coefficient	Sig
Fabric count, warp	-0.537	0.001*	-0.582	0.000*
Fabric count, filling	-0.670	0.000*	-0.525	0.002*
Stretch, warp	0.624	0.002*	0.635	0.002*
Stretch, filling	0.543	0.009*	0.725	0.000*
Growth, warp	0.601	0.003*	0.624	0.002*
Growth, filling	0.585	0.004*	0.696	0.000*
Roughness, warp	0.473	0.005*	0.446	0.009*
Roughness, filling	0.446	0.009*	0.407	0.019**
Cover	-0.446	0.009*	-0.438	0.011*

* significant at $\alpha \leq 0.01$
** significant at $\alpha \leq 0.05$

For conservators, electrostatic cling is important because of static electricity's tendency to attract charged particulate soil from air borne dust and environmental pollution. A fabric covered with an overlay that has high electrostatic potential and placed on display in an environment without strict air filtering and adequate housekeeping would attract particulate soils. If the sheer fabric had a low degree of cover, those soils would fall through the fabric interstices onto the textile. The attracted soil could contribute to the deterioration of both the historic textile and the overlay fabric. Sheer overlay fabrics with low electrostatic cling would be best for objects displayed in facilities without effective environmental controls.

Stiffness

The data indicated that nylon net was the stiffest fabric when measured in the warp direction, while polyester net was the stiffest in the filling direction. Polyester georgette and the English nets were the least stiff in both directions. See Figure 48. Not all of the fabrics had higher stiffness ratings in the warp direction than the filling. One-way ANOVA comparing the means for all eleven fabrics indicated that

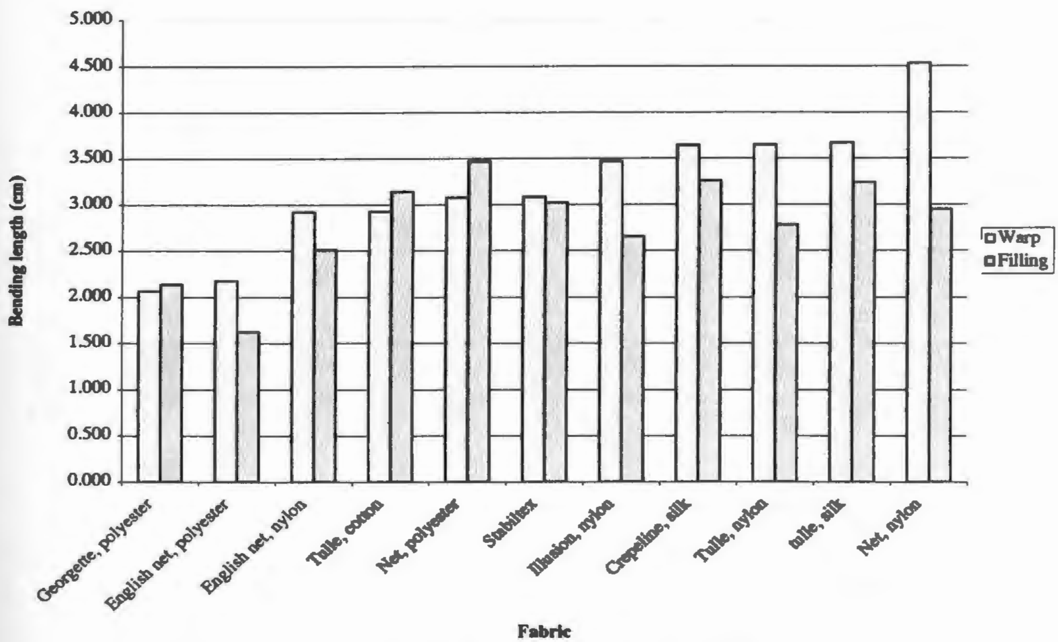

Figure 48. Stiffness of overlay fabrics

Table 31. Stiffness, warp, Tukey's HSD homogeneous subsets (alpha = 0.05)

Group	Sig	Lowest	Polyester georgette	Polyester English net	Nylon English net	Cotton tulle	Polyester net	Stabiltex	Nylon illusion	Silk crepeline	Nylon tulle	Silk tulle	Nylon net	Highest
1	1.000													
2	0.052													
3	0.052													
4	0.206													
5	1.000													
Fiber			polyester	nylon	polyester	cotton	polyester	polyester	nylon	silk	nylon	silk	nylon	
Fabric structure			woven	raschel	raschel	raschel	tricot	woven	tricot	woven	tricot	raschel	raschel	
Yarn			multi	multi	multi	staple	mono	multi	mono	multi	mono	multi	multi	

Table 32. Stiffness, filling, Tukey's homogeneous subsets (alpha = 0.05)

Group	Sig	Lowest	Polyester English net	Polyester georgette	Nylon English net	Nylon illusion	Nylon tulle	Nylon net	Stabiltex	Cotton tulle	Silk tulle	Silk crepeline	Polyester net	Highest
1	0.494													
2	0.177													
3	0.057													
4	0.116													
Fiber			nylon	polyester	polyester	nylon	nylon	nylon	polyester	cotton	silk	silk	polyester	
Fabric structure			raschel	woven	raschel	tricot	tricot	raschel	woven	raschel	raschel	woven	tricot	
Yarn			multi	multi	multi	mono	mono	multi	multi	staple	multi	multi	mono	

significant differences in stiffness exist between at least two fabrics ($p<0.01$). Tukey HSD analysis produced five homogeneous subsets (not necessarily mutually exclusive) in the warp direction. See Table 31. Nylon net, the stiffest fabric, was significantly different from all other fabrics in the warp direction. Polyester georgette and polyester English net, the least stiff, were significantly different from all other fabrics in the warp direction but not from each other. The other three subsets in the warp direction were highly overlapping and had high degrees of mean separation within their subsets.

Tukey HSD analysis produced four subsets in the filling direction. See Table 32. Polyester English net and polyester georgette, the least stiff in the filling direction, were not significantly different from each other. In the second subset, polyester georgette was not significantly different from nylon English net, nylon illusion, and nylon tulle – one raschel and two tricot knits. The three large subsets in the filling direction were highly overlapping and had high degrees of mean separation within their subsets.

Statistical correlation coefficients were calculated using Spearman's rho for the stiffness data paired with other variables. Stiffness did not correlate with abrasiveness or any other variables except thickness and weight. Stiffness correlated negatively with thickness and weight. See Table 33. The confounding variable of finish might be a factor in these results as a finish, which imparts stiffness might also add weight and thickness to a fabric.

Table 33. Stiffness correlation coefficients

	Thickness		Weight	
Stiffness	Coefficient	Sig	Coefficient	Sig
Warp	-0.312	0.003*	-0.779	0.000*
Filling	-0.587	0.000*	-07.15	0.00*

* significant at $P \leq 0.01$

The stiffness test results create more questions than they resolve. What happens to the fabric stiffness if it is washed before being used? When a conservator desires some stiffness to stabilize a fragile textile, is it safe to leave an unknown chemical finish in the overlay fabric and hope that it is stable in the long term? The knowledge that fabrics have different stiffness in the warp or filling direction can be put to good use in conservation. Overlay fabric can be applied with its stiffest direction corresponding to the stiffest direction of the fragile fabric to re-create the original hand or drape of the fabric or it may be applied with the stiffest direction of the overlay along the weakest direction of the fragile fabric to provide some stability. For example, an overlay on a skirt, which will be exhibited on a mannequin, should have the stiffness of the overlay correspond with the stiffness and hand of the original skirt fabric so as not to change the drape of the costume. A flat textile with a loss of yarns and loss of structural integrity in the warp direction would benefit from having an overlay with stiffness applied in the warp direction to supply stability. Conservators should consider both the stiffness of an overlay fabric and also the direction of the stiffness and use that knowledge to enhance treatment outcomes.

Overall Performance Results

Table 34 summarizes the relevant fabric characteristics and the results of the performance tests conducted in this research. A textile conservator can use this data to evaluate the fabrics now being used as overlays or to determine the best use of a new fabric. By matching fabric characteristics on the table to those of a different fabric not evaluated in this research, the conservator also can predict how it would perform.

The photomicrographs on pages 48 and 49 can be used in conjunction with this table to identify the important structural characteristics of a specific fabric. Using a binocular microscope or a high-powered magnifying glass, a conservator can determine the shape and size of the interstices in any sheer fabric. The interlacement pattern of the yarns can be compared to the photographs in this research, and then the performance characteristics of that type of fabric can be looked up on Table 34. This summary of information has not been available before to help conservators make an informed choice.

Table 34. Summary of performance test results

Fabric Characteristics	Crepeline, silk	English net, nylon	English net, polyester	Georgette, polyester	Illusion, nylon	Net, nylon	Net, polyester	Stabiltex	Tulle, cotton	Tulle, nylon	Tulle, silk
Yarn structure	multi-filament	multi-filament	multi-filament	multi-filament	mono-filament	multi-filament	mono-filament	multi-filament	staple	mono-filament	multi-filament
Yarn spin	medium	medium	-	high	-	-	-	low	medium	-	-
Fabric structure	woven	raschel knit	raschel knit	woven	tricot knit	raschel knit	tricot knit	woven	raschel knit	tricot knit	raschel knit
Performance Tests											
Abrasiveness	low	medium	low	lowest	medium	highest	medium	medium	high	medium	high
Cover	medium	medium	high	highest	low	lowest	medium	medium	high	low	medium
Friction, filling	medium	high	low	medium	medium	medium	lowest	highest	medium	medium	high
Friction, warp	low	medium	high	medium	highest	medium	lowest	medium	low	high	medium
Gloss	high	medium	medium	medium	low	medium	low	highest	lowest	low	low
Growth, filling	very low	medium	medium	least	medium	broke in test	medium	least	low	highest	medium
Growth, warp	least	medium	medium	very low	highest	low	medium	least	medium	medium	high
Static cling, filling	medium	medium	medium	none	very high	low	very high	very low	none	very high	very high
Static cling, warp	low	medium	medium	none	high	low	very high	very low	none	high	very high
Stiffness, filling	high	medium	lowest	low	medium	medium	highest	medium	high	medium	high
Stiffness, warp	high	medium	low	lowest	high	highest	medium	medium	medium	high	high
Stretch, filling	least	medium	most	very low	medium	high	medium	least	low	high	medium
Stretch, warp	least	medium	low	very low	most	medium	medium	least	medium	medium	high
Surface roughness, filling	low	medium	medium	lowest	medium	medium	medium	low	medium	medium	highest
Surface roughness, warp	lowest	high	highest	low	medium	medium	low	low	medium	medium	medium
Thickness	thinnest	thick	thickest	med-thin	med-thin	med-thick	med-thick	thin	med-thick	med-thin	thick
Weight	medium	medium	heaviest	heavy	lightest	medium	medium	medium	heavy	light	medium

CHAPTER 5

CONCLUSION

The physical and mechanical properties of sheer fabrics affect their abrasiveness and their performance as overlays in conservation. Complex relationships exist between fabric end-use characteristics and fabric mechanical behavior (Schick 1977). When selecting a fabric for a given purpose, a person must "assess many properties simultaneously and subjectively and rank the fabrics in order of preference" (Booth 1969 p. 282). This research assessed the properties of sheer overlay fabrics to assist conservators in matching the characteristics of the textiles to the needs of the fragile object being conserved.

The primary objective of this research was to compare the abrasiveness of sheer overlay fabrics and to identify predictor properties for abrasiveness. This research also analyzed and compared performance properties of the sheer textiles to provide conservators with objective data. Statistical analysis showed significant differences between fabrics and significant correlations between properties.

Analysis of variance found a significant difference between at least two of the fabrics tested for abrasiveness. Nylon net was the most abrasive fabric; polyester georgette was the least abrasive fabric. The three woven fabrics tested were all at the low end of the abrasiveness scale. The cotton tulle, with yarns of staple-length fiber in a raschel knit, ranked high in abrasiveness. The silk tulle and nylon tulle, a raschel and a tricot knit, also ranked high in abrasiveness. The type of filament yarn, mono-filament versus multi-filament, did not affect abrasiveness, nor did raschel versus tricot knit structure. Hexagonal versus diamond shaped interstices in the knitted nets did not affect abrasiveness. Due to the method of testing abrasiveness, the differences between fabrics were small, but Tukey HSD analysis showed a significant difference in abrasiveness between the most abrasive fabric, nylon net, and the two least abrasive fabrics—polyester georgette and polyester English net. Conservators should not choose nylon net for use as an overlay because the abrasiveness of the overlay could damage the fragile or historic textile.

Predictor properties for abrasiveness were identified using Spearman's correlation coefficients. Cover factor and fabric count both correlated negatively with abrasiveness; stretch and growth correlated positively. A fabric with low cover, low fabric count, and high stretch and growth is predicted to have high abrasiveness. The properties of cover, fabric count, and stretch/growth can be determined without sophisticated measuring instruments and can be assessed by conservators when choosing fabrics. The research did not show a relationship between abrasiveness and fabric friction, surface roughness, stiffness, or static cling. These findings are consistent with research by Harlock (1989) where he found no relationship between surface roughness and abrasiveness. In addition, no correlation existed between abrasiveness and thickness or weight. This lack of correlation is contradictory to results by Simpson (1993) who found that heavier and thicker fabrics were more abrasive. Simpson was testing backing fabrics that usually are heavier than overlay fabrics. All fabrics in this research were lightweight sheer textiles.

This research identified and quantified other properties of the sheer fabrics. Table 34 summarizes these properties. Results of the pre-study survey done by this author indicated that conservators consider sheerness to be the most important criterion in choosing overlay fabrics. This research ranked overlay fabrics for sheerness using cover factor as a measure. Fabrics also were ranked using fabric count, in yarns per inch for wovens and hex per inch for knits. Both cover and fabric count can be used to assess sheerness. Nylon net had the lowest cover and fabric count; cotton tulle had the highest cover and fabric count of the knits. The three wovens had higher fabric counts than the knits, but polyester Stabiltex and silk crepeline ranked in the mid-range for cover. Polyester georgette, with the highest cover of all the fabrics, had the highest fabric count. One multi-filament knitted net with large interstices and three mono-filament knitted nets ranked the lowest for cover and could be chosen if sheerness were the only criterion.

Fiber content and color ranked as the next most important criteria for choosing overlay fabrics. These two factors can be assessed by conservators at the point of purchase. Yarn characteristics and fabric structure contributed more to differences between sheer fabrics than did fiber content. Fiber content does affect the longevity of sheer fabrics; both silk and nylon deteriorate with exposure to sunlight (Collier and Tortora 2001).

The fourth ranked criterion of conservators was fabric hand. Hand is a very subjective characteristic, but some properties help interpret the feel and drape of a textile. Stiffness and surface roughness were used as objective measures in this research to assess hand. Surface roughness varied in the warp and filling direction, and this orientation may affect the hand of the fragile fabric in the completed treatment. Fabric structure, including type of knit, played an important role in surface roughness. The two English nets had the highest surface roughness in the warp direction; silk crepeline had the lowest. The three tulle fabrics had the highest surface roughness in the filling direction; polyester georgette and silk crepeline had the lowest.

Stiffness also was different in the warp and filling directions for several fabrics. Incomplete information about the finishes used on the fabrics in this research and their impact on the stiffness results indicates the need for further research in this area. In this research, nylon net was the stiffest fabric in the warp direction; polyester net was the stiffest in the filling direction. Polyester georgette and polyester English net were the least stiff in both warp and filling directions. Conservators should be aware of the differences in stiffness in warp and filling directions and use that knowledge to better match sheer overlays to an object's needs.

Since both surface roughness and fabric stiffness affect the hand of a fabric, the addition of an overlay should be done to match the hand of the original fabric as closely as possible. On objects that will be framed or kept flat, the need to match the hand of the overlay and original fabric is not critical, but for a fabric that will drape such as a skirt or a set of draperies, the overlay should match the hand and drape of the object to preserve the original feel and look of the fabric. An overlay that will form to the surface of the object will be less noticeable than one which stands stiffly away from the surface of the fragile textile. An overlay that molds to the surface will do a better job at keeping small bits of damaged fabric in place than will one which stands away.

Elongation and elastic recovery, measured as stretch and growth, were assessed as indicators of strength and stability. The three woven fabrics—Stabiltex, silk crepeline, and polyester georgette—had the least stretch and growth of all the fabrics. Of the knits, nylon illusion had the most stretch in both warp and filling directions; polyester English net had the least stretch in both directions. Growth is a measure of how easily a fabric returns to its original length after a stretch with constant load and time. The nylon net broke before the end of the test in the filling direction and growth could not be tested. This breakage indicated that it is not a stable fabric under the stress of four pounds of load. In half of the tests, the nylon illusion broke in the warp direction. Despite the breakage, nylon illusion had the greatest growth in the warp direction; nylon tulle had the greatest in the filling direction. Of the knits, polyester English net had the least growth in the warp direction; cotton tulle had the least in the filling direction. Conservators should take the low strength of nylon net and nylon illusion into account when choosing appropriate overlays for a specific treatment. The fabrics that rated high for growth do not provide enough stability to function well as overlays that provide support for a fragile textile.

Thickness, weight, gloss, and static cling also were assessed and ranked in this research. Any of these properties could be important in a particular overlay application in conservation. These data are available in Table 34 to make selection of a sheer fabric more objective for the needs of each project.

This research also found that yarn structure is central to the gloss rating of a sheer fabric. The highest gloss fabrics were the fabrics made of large diameter multi-filament yarns with little twist. The least glossy fabric was the cotton tulle, made of staple-length cotton fiber. Two of the mono-filament yarn fabrics, nylon illusion and tulle, also were low in the gloss ranking; the third mono-filament, nylon net, ranked higher because it had no added delustrant.

Using image analysis software to measure cover, as was done in this research, may prove to be easier and more accurate than the formula previously used to calculate cover. Certainly, the image analysis software allows cover to be determined for knits and non-woven fabrics in a way that was previously not possible.

The knitted nets made of mono-filament yarns in this research had high electro-static cling results. This indicates that they could easily build up a charge and attract airborne charged particulates to their vicinity. These particulates could be damaging to the fragile object through third-party abrasion or chemical degradation.

Based on this research, nylon net has the lowest cover of all the fabrics tested, but it also is the most abrasive and had the highest warp direction stiffness. It had high stretch and was so weak that it broke during testing before growth could be assessed. The nylon fiber degrades easily in sunlight. This combination of characteristics makes it the worst choice for conservators to use as a sheer overlay for fragile and historic fabrics. The best choice of sheer fabric for an overlay is dependent on the needs of the object being conserved and the characteristics of each fabric—balancing sheerness needs with the other properties tested.

The manufacturing and retail nomenclature for the textiles in this research is not consistent with their yarn and fabric structures. For example: three fabrics in this research are marketed as tulle: two of them are raschel knits; one is a tricot knit. Two of them have hexagonal meshes; one has a diamond shaped mesh. One is made of mono-filament yarns, one of multi-filament, and one of staple-length fibers. One cannot simply write in a report that tulle was used in the treatment of an object. Fiber content, fabric structure, yarn structure, and finish information also are needed to communicate the specific nature of the overlay fabric used. Even the warp or filling orientation of the overlay treatment is useful information to be included in conservation reports for replication of results or future treatments. For these same reasons, care must be taken when extrapolating the results of this research to other fabrics in the market-place; specific characteristics should be matched rather than just fabric names.

The finishes applied to the fabrics in this research could be a confounding factor for a number of properties—most notably stiffness and coefficient of friction. Information about the finishes on most of the fabrics was not available. Additional research into the finishes used on sheer overlay fabrics and the affect of the finishes on fabric performance is needed. Research into the ageing properties of sheer overlay fabrics also could provide valuable information to help conservators make informed choices for overlay fabrics, particularly if the object will be exposed to light and/or changing environmental conditions.

Sheer overlay fabrics are no different from other textiles in that they have complex relationships between the yarn and fabric structures and their mechanical behavior. This research provides some insight into those relationships and offers conservators objective data to differentiate between fabrics. Because each fragile or historic object requiring treatment has a set of unique needs, these data are provided to assist conservators in matching the performance properties of the sheer fabrics to these needs.

APPENDICES

APPENDIX A

SURVEY OF TEXTILE CONSERVATORS

Purpose

An Internet-based survey began this research. The survey determined how often professional conservators and restorers use sheer overlays in their treatments and which fabrics they most frequently used. Survey questions asked about reasons for their choice of a particular fabric, type of treatments that incorporated sheer overlays, selection of fabric over the last ten years, and techniques such as dyeing, painting, and adhering overlays. After demographic questions such as educational background and geographic location of the conservator/restorer's practice, an open ended eleventh question allowed respondents to add additional information to the survey. Many of the other questions also included an open-ended final choice so that respondents could provide additional information throughout the survey.

Methodology

Graduate students in the Department of Textiles, Fashion Merchandising, and Design at the University of Rhode Island pre-tested a multiple-choice draft of the survey in April 2003. After editing and the insertion of additional answers, a number of volunteers pre-tested a web-based version of the survey to ensure its compatibility with a variety of computers, operating systems, and respondents' Internet skill levels. The University of Rhode Island Internal Review Board (IRB) approved the use of the survey on human subjects.

An Internet-based survey provided a larger potential audience at lower cost than a mailed survey. Sixty members of the American Research Association, when queried about online surveys, responded positively about their use particularly because of their cost savings and the ease of data analysis (Gunn 2002). The questionnaire, converted to a web-compatible html format, was posted to the Internet on a site hosted by an Information and Instructional Technology Services professional at the University of Rhode Island. All data went directly into a data collection spread sheet, so that the answers remained completely anonymous.

Mailing lists of textile and conservation organizations provided the e-mail addresses of textile professionals who had indicated that they worked or had an interest in conservation or restoration. The organizations included the Textile Society of America, the Costume Society of America, American Institute for Conservation, and the American Quilt Study Group. The researcher or her major professor was a member of these organizations. The Internet provided additional email addresses for businesses and individuals who advertised themselves as being textile or quilt conservators or restorers on the web.

All people with email addresses found from the various sources received the survey. IRB-approved email messages sent to the identified names described the nature of the survey. See Appendix B for a copy of the letter and a paper copy of the survey. The email message asked the respondents to click on a link that took them directly to the survey. Of the 378 original e-mails sent out, 115 were returned by servers as being undeliverable; therefore, 263 were delivered. Forty-three surveys were returned for a response rate of 16%. While Internet-based surveys are a quick way of gathering data, response rates of 60% or better still are recommended. Malaney recommends follow-up procedures such as e-mail and/or telephone reminders as ways to increase the response rate and ensure an accurate sample of the population (Malaney 2002). This research project did not use any follow-up procedures; therefore, the results should not be extrapolated to the entire population of textile conservators.

Two professionals transcribed the survey into html, hosted the survey on a website, and translated the data gathered into a database. Gunn discussed potential problems that can occur in the translation from paper survey to the html version such as different size text boxes, randomizing question order, error checking, and character codes appearing in responses. Differences in the presentation of the survey, based on differences in the respondent's computer, Internet browser, and computer skills also can play a role in the accuracy of responses (Gunn 2002).

Results and Discussion

Answers to the first three survey questions provide information about the use of sheer overlays in conservation treatments and the fabrics chosen. The opening question of the survey inquired if conservators use sheer overlays in their professional practice. All respondents (43) answered question 1 and its follow-up question 1A. Most (36 respondents, 83.7%) stated that they use sheer overlays. See Figure A1. The follow-up question asked, "What fabrics do you use?" and listed six fabric choices, plus an open-ended "other" option in which respondents could add additional fabrics in the

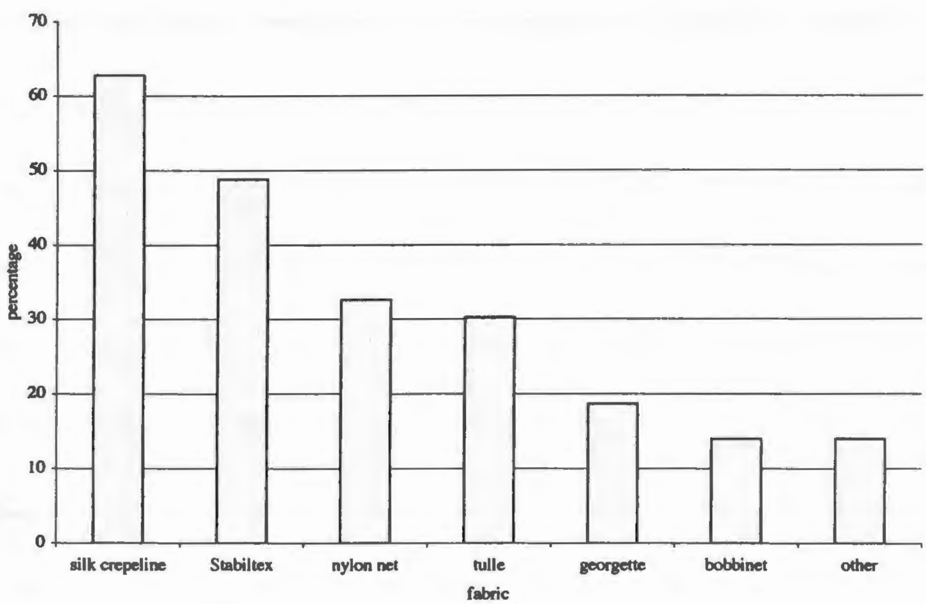

Figure A1. Frequency of fabric use

space provided. They could check "all that apply," so the percentages obtained in the analysis do not add up to 100%. More than half (27 respondents, 62.8%) used silk crepeline, nearly half (21 respondents, 48.8%) used Stabiltex (also known as Tetex), 14 (32.6%) nylon net, 13 (30.2%) tulle, 8 (18.6%) polyester georgette, 6 (14%) bobbinet, and 6 (14%) stated that they use other fabrics.

The "other" fabrics response included one respondent each using: allusion [sic] - nylon/poly net; batiste, hand-woven linen cheese cloth; cheesecloth, melt-bond polyester non-wovens; silk to replace silk; stretch nylon; and vintage silk organza and cotton voile salvaged from nineteenth-century garments.

Silk crepeline was the fabric used most often by the conservators surveyed. Polyester Stabiltex was the second most used, with nylon net and tulle being the third and fourth choices respectively. This is an expected result based on a review of the literature, attendance at professional conferences, and anecdotal information. However, results may be distorted because fabrics may have several names and/or may be defined differently in different parts of the world or the United States by users and suppliers. The survey itself may have caused some confusion in this area because it specified the fiber content of three fabrics—polyester georgette, nylon net, and silk crepeline, did not specify the fiber content of two—bobbinet and tulle, and used a brand name for a third—Stabiltex. Descriptions of the fabrics were not given in the survey so respondents needed to use their own knowledge of fabrics to identify each one. This may have biased the data towards the three best-defined choices, Stabiltex, silk crepeline, and nylon net.

The original intent of the survey was to use the results to choose the fabrics for performance testing. The results indicated that conservators and restorers used all six of the fabrics in the survey, so all were included. Illusion and polyester net were added because they were mentioned in the survey. Two types of bobbinet were found in the marketplace, both called English net, but of different fiber contents, nylon and polyester, so both were used. Tulle was found in silk, cotton, and nylon and all three were included, making a total of eleven fabrics in the research.

The second survey question asked, "What criteria do you use to choose an overlay fabric?" with eleven possible answers arranged alphabetically plus the option of choosing "other" and filling in additional information. This question also used "check all that apply" so the data do not add up to 100%. All respondents (43) answered question two. See Figure A2. Nearly three quarters (31 respondents, 72.1%) of respondents noted that translucency/sheerness was a criterion to use. Fiber content was critical to 29 (67.4%) respondents. Color was important to 27 (62.8%) respondents and 22 (51.2%) considered the hand and strength of the fabric. Availability was a criterion for 20 (46.5%) in selecting fabric for sheer overlays. While 16 (37.2%) considered dyeability, 13 (30.2%) used the weight of the fabric, and 11 (25.6%) considered cost of the fabric when choosing overlays. Six (14%) used tradition, and 4 (9.3%) thought about the width of the fabric when making their decision about which fabric to use. Fourteen percent of respondents used other criteria.

Comments detailing other criteria for choosing fabric included overall look of the artifact at a distance of six feet, ease of application, fragility of object being treated, museum lighting, stability, resistance to deterioration, support to protect the subject fabric, transparency of fabric, acid-free status of fabric, and criteria of the object's owner or curator.

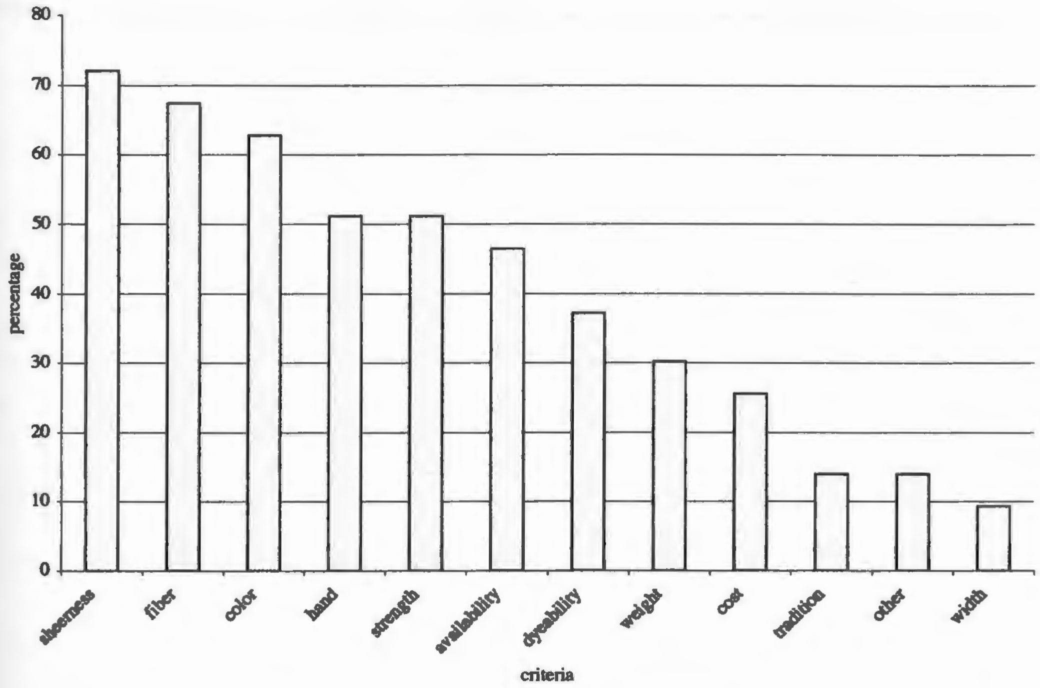

Figure A2. Frequency of criteria used to choose sheer fabrics

As expected, respondents identified sheerness as the most important factor in choosing a fabric for an overlay. They chose fiber content and color as the next most important criteria. Hand, strength, and availability formed a second tier of criteria with half of the respondents identifying them. Dyeability, weight, and cost were less important. Traditional use and width of fabric were the least valuable criteria. The respondents probably use a combination of criteria based on the requirements of the specific project and the desires of the owner/curator of the object.

Answers to the third question established the projects and objects on which conservators use sheer overlays. The question included seven object categories and both "check all that apply" and the open-ended "other" options; the totals do not equal 100%. All respondents (43) answered this question. See Figure A3. Twenty-four (55.8%) use sheer overlays on costumes and apparel. They frequently used

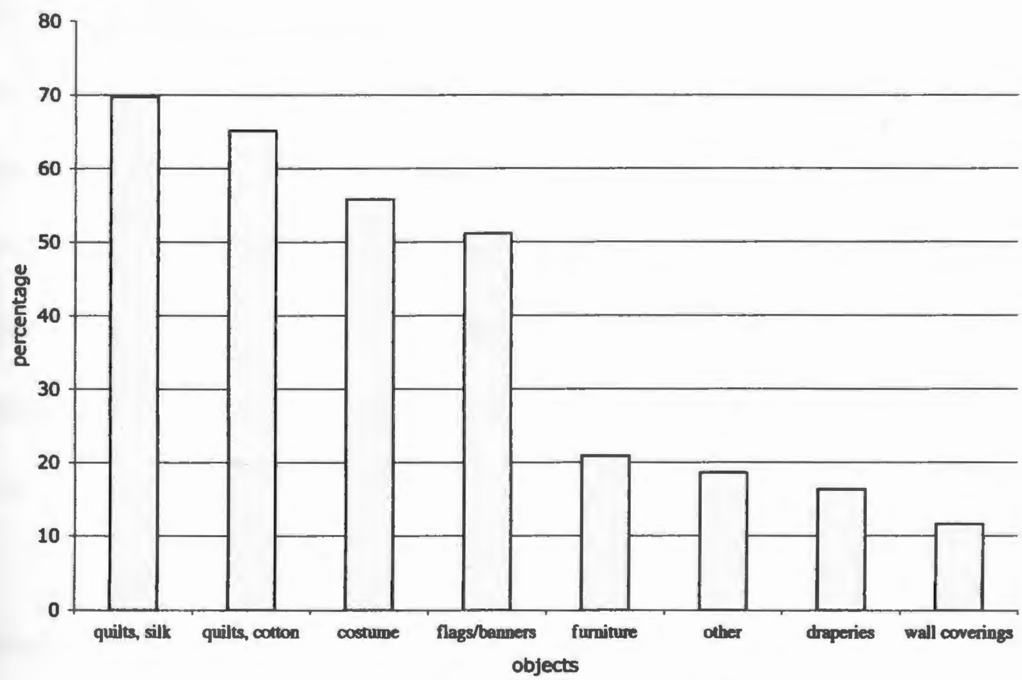

Figure A3. Frequency of objects treated with sheer overlays

overlays on quilts, with 28 (65.1%) using overlays on cotton quilts and 30 (69.8%) using overlays on silk quilts. Half (22 respondents, 51.2%) of respondents apply overlays to flags and banners, while 7 (16.3%) use overlays on draperies, 5 (11.6%) on wall coverings, and 9 (20.9%) on upholstered furniture. Other was chosen by 8 respondents (18.6%).

Respondents who completed the “other” category listed a variety of possible objects including archaeological textiles, ethnographic objects, and wall hangings. Respondents also commented that they used overlays on a number of accessories such as hats, fans, shoes, gloves, and stocks. Two respondents stated that they placed overlays on embroideries, and one listed tapestries and linens as well. Two respondents placed overlays on lace; one of these mentioned using sheer fabric as an underlay under lace. One respondent stated "you could use overlays on all types of textiles." The survey should have included accessories as a choice for type of object. Respondents may have included these objects in the costume/apparel category or not have thought of them at all. Clearly, conservators use overlays on a variety of textile projects. An additional follow up question could have determined the purpose of sheer overlays for each category of objects, but the question was not asked in the survey.

Answers to the next four questions determined if conservators pre-treat the overlay fabrics to enhance the effectiveness or aesthetic quality of the final treatment. Question four asked about the use of adhesives with overlays. Ten respondents (23.3%) had used adhesives with sheer overlays; 26 (60.5%) did not use adhesives, and 7 (16.35%) did not answer the question. Eleven conservators answered a follow up question about the types or brands of adhesives used. One person stated that it "depends on the project.” One respondent reported using adhesives "only for sticky threads." Of those mentioning a specific product, five mentioned Lascaux 340, 360, or 498 and a combination of 360 and 480. Beva film, Beva D-8, and Beva 371 were included, as well as Elvase, Clariant T1460, and Fine Fuse.

The fifth survey question asked if conservators painted on the surface of sheer overlays. Most (30 respondents, 69.8%) said that they did not paint on sheer overlays; 5 (11.6%) did, and 8 (18.6%) did not answer the question. The follow up question asked, "On what type of project(s) do you use paint?" Six conservators offered additional information. Water-based Versatex and acrylic were named as types of paint used by two conservators. The objects that they had painted overlays for included paintings on textiles and painted medallions on flags, as well as banners, flags, quilts, costume, and "things with patterned fabric."

Question six asked conservators about dyeing overlay fabrics to match a particular project. See Table A1. Half (22 respondents, 51.2%) stated that they sometimes dyed the overlay fabrics; 14 (32.6%) did not dye sheer fabrics, and 7 (16.3%) did not answer the question. The follow up question asked, "What percentage of your overlay projects do you dye to match?" Eighteen who responded positively gave the percentage of the time that they dye. The conservator who dyes 95% of the time commented that the "only time I don't [dye] is when using Tetex and it is the correct color."

Table A1. Number of conservators who answered the dye follow-up question

Respondents estimate of percent of time overlays are dyed by them	Number of conservators who responded with a percentage
1-2%	5
5%	4
10-20%	3
50-60%	2
70-85%	2
95%	1
100%	1
Total	18

Question seven asked whether the respondents had been doing conservation work ten years ago. Over half (25 respondents, 58.1%) answered positively, while 11 (25.6%) had not been doing conservation work ten years ago and 7 (16.3 %) did not answer the question. See Figure A4. Question 7A asked those respondents who answered yes to question 7, which type of sheer overlay fabrics they used ten years ago. The ranking of fabrics was the same as fabrics in current use, with silk crepeline being used the most frequently and Stabiltex a close second. All of the fabrics had an increase in usage with the average increase being 11.9% with a range of 7% increase for bobbinet to 18.6% increase for silk crepeline. Respondents had an open-ended choice of "other" for the overlays used 10 years ago; answers included cheesecloth and vintage silk and cotton organza/voile salvaged from 19th-century garments.

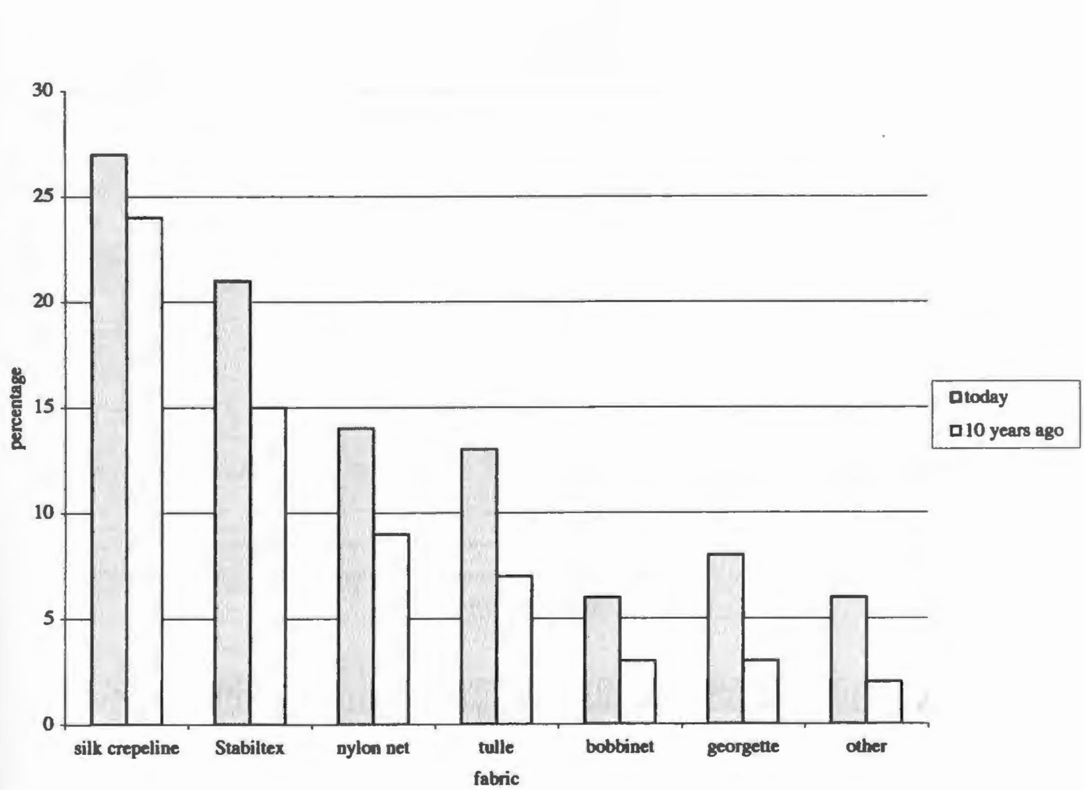

Figure A4. Overlay fabric used today compared to ten years ago

Questions eight through ten involve demographics. All respondents (43) answered all of the demographic questions. Question eight queried the type of conservation/restoration practice of each respondent. See Figure A5. The majority (30 respondents, 69.8%) were in private practice, 9 (20.9%) worked in a large museum, 7 (16.3%) worked in a small museum, 5 (11.6%) respectively worked in a government agency or at a University and 2 (4.7%) worked in another setting. Because this was not a random sample, knowing if this is representative of the profession is not possible.

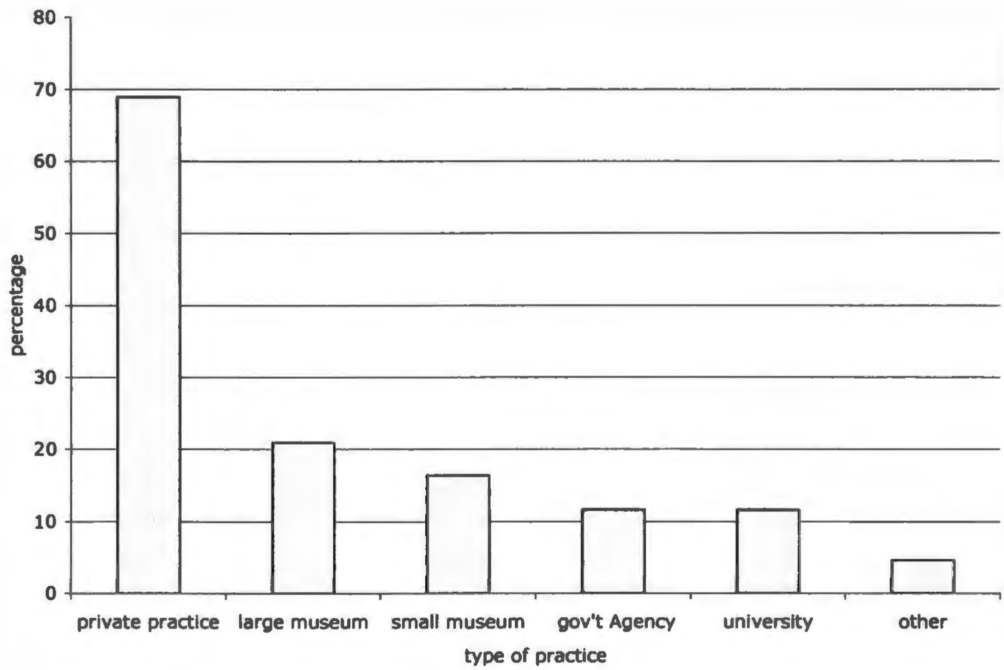

Figure A5. Frequency of type of conservation/restoration practice

Educational background was the focus of question nine. The question asked "How did you acquire your conservation/restoration expertise?" See Table A6. Seventeen received their training at US or Canadian Universities, one at a European university. Twenty-one were self-taught in the US or Canada, and one was self taught in Europe. Nine received training at other Canadian or American institutions and one at other institutions in Europe. Due to the small number of responses (3) from outside of North America, drawing any conclusions about differences in education from European and other sources is difficult and, therefore, the rest of the analysis will only involve responses from North America. Respondents could select one or more of the above choices and also "other," therefore the total number of responses adds up to more than the total number of respondents. Of the eleven respondents answering "other" to question nine, several had a combination of educational backgrounds. They frequently listed internships, mentorships, and apprenticeships. Workshops, classes, and seminars also were mentioned.

Table A6. Type and location of conservation education

Type	Location	Number	Percentage
Self-taught	US or Canada	21	42
	Europe	1	2
University	US or Canada	17	34
	Europe	1	2
Other	US or Canada	9	18
	Europe	1	2
Total responses		50	100%

Question ten asked about the geographic location of the conservation or restoration practice. See Table A3. Most of the respondents were from the United States due the use of address lists from American member organizations as the basis for the mailing list. The higher density of museums in the northeastern U.S. may explain the larger number of conservators located there. Unfortunately, some of the U.S. respondents did not choose one of the categories given for geographic location and chose "other" instead. This means that their answers are not included elsewhere in the analysis when geography is related to fabric use. They did explain where they were from, and this information should be taken into account for the geographic divisions offered in future surveys. The respondents were not restricted to only one response, and the number of responses to this question is greater than the total number of respondents.

Table A3. Location of Conservation Practice

Location	Number	Percentage
United States		
Northeast	14	28
Southeast	7	14
Midwest	10	20
West	12	24
Subtotal	43	86%
Asia	1	2
Canada	1	2
Europe	1	2
Other		
Australia	1	2
Eqypt	1	2
Southwest US	1	2
Mid-atlantic US	1	2
Total responses	50	100%

Question eleven was a completely open-ended question allowing respondents to add "additional comments about the use of sheer overlays in textile conservation." Eighteen respondents provided comments. One defined an overlay as a treatment that "is not weight bearing" and stated that fiber content is not important because "hanging behavior" is not an issue without bearing weight. Two commented that they had used overlays very few times or none at all because their practice did not have a need for it. A private practitioner mentioned that the varied needs of the clients, and the intended end use often dictated his/her choice of overlay materials. Another stated that he/she usually chose silk over Stabiltex because the quilts he/she worked on would be moved, folded, and used frequently. A bad experience with the use of overlays on silk quilts was related in one comment: "using the overlays on quilts ... created little sacks which would hold additional bits of silks, etc, which were shattering. After a few years, this was worse looking than nothing."

Respondents used the space to ask questions: "I need a source for bobbinet" and "I need to know about the stitches people use in attaching overlays, how to handle edges, etc." One respondent provided suggestions for attachment: "use very fine needles, working by hand, with magnifying glass if necessary: rarely do I turn under edges, never with netting." One respondent liked that the fact that fabrics could be stabilized with overlays "without too much sewing and over-handling." Another commented that one needed to be sure that the original textile or garment was "strong enough to withstand sewing or adhesive attachment." One mentioned that nylon and bridal net are "not inappropriate when used in a museum setting with controlled exhibition scheduling and light levels." He or she also liked the fact that overlays were available in an "enormous quantity of colors, are cost effective, and are easy to apply and take off." A respondent expressed concern that an overlay alone does "nothing to actually stabilize a fragile textile" but suggested that using an adhesive treatment with the overlay would provide the needed stability. One person complained that the cost of fabrics was so high that small museums could not afford to use sheer overlays.

Cross-Tabulations

Cross-tabulation analysis examined trends in the data. This is a useful method for describing the interactions between the various questions. Questions such as "how many conservators who practice in the northeastern United States use Stabiltex?" can be answered using cross-tabulations. No statistical analysis was performed on these data.

The respondents' criteria for choosing fabrics was crossed by each fabric used and by the category of objects conserved. For example, a cell in a table was created by counting the number of conservators who use silk crepeline and also chose sheerness as a criteria. Because conservators could choose more than one answer to every question, none of the rows or columns adds to the total number of respondents. Cross-tabulations also were used on the survey responses to understand changes in fabric choice over time, geographic influence over fabric choice, educational influence over fabric choice, and workplace influence over fabric choice.

The cross-tabulation analysis showed that conservators who work on all categories of objects except upholstery choose silk crepeline most frequently. See Table A4. Stabiltex is the most frequent second choice. Upholstery conservators use Stabiltex as their first choice, with silk crepeline as second choice. Nylon net is the third choice for all objects but is used less than half as often as the first two choices.

Costume conservators use georgette more often than other object conservators do. Quilt and costume conservators also use

Table A4. Conservators classified by objects conserved and fabrics used

	Object						
Fabric	Quilts, silk	Quilts, cotton	Costume	Flags	Upholstery	Draperies	Wall coverings
Silk crepeline	25	22	21	21	8	7	4
Stabiltex	19	17	18	19	9	6	3
Nylon net	12	11	11	9	5	4	2
Tulle	11	10	8	7	2	2	2
Bobbinet	6	5	5	4	3	2	2
Georgette	6	6	8	6	2	1	2

bobbinet and nylon net more than other conservators. Quilt conservators use tulle more often than others do. The small number of total responses from wall covering and drapery conservators makes drawing accurate conclusions from their data difficult.

Eleven criteria for choosing fabric were given as choices in the survey plus "other." Respondents could select as many criteria as they felt were important. See Table A5. Fiber content, sheerness, color, and hand were the criteria identified as

Table A5 Responses classified by selection criteria and fabrics selected

Selection Criteria	Fabric Selected					
	Silk Crepeline	Stabiltex	Nylon net	Tulle	Georgette	Bobbinet
Sheerness	23	19	13	12	7	6
Fiber	23	17	12	10	5	6
Color	20	15	11	11	8	4
Hand	19	12	9	9	5	5
Strength	17	14	8	7	6	4
Dyeability	16	11	7	3	3	3
Availability	14	11	7	7	3	2
Cost	9	6	5	4	4	1
Weight	9	8	5	6	4	2
Tradition	6	4	3	3	2	2
Width	4	3	2	0	1	1
Other	4	5	4	2	3	2

most important to silk crepeline users. Stabiltex users cited sheerness, fiber content, color, and strength. Nylon net users cited sheerness, fiber content, color, and hand as their chosen criteria. Those respondents who currently use tulle in their practice chose sheerness, fiber content, color, and hand as criteria. Polyester georgette was chosen because of color, sheerness, strength, fiber content, and hand. Bobbinet users cited sheerness, fiber content, hand, and color as the most important criteria for making fabric choices.

The same cross tabulations can be evaluated from a different perspective, Those respondents who said that sheerness was an important criterion chose silk crepeline and Stabiltex most often with nylon net and tulle forming the next tier of choice. Silk crepeline and Stabiltex were chosen when fiber content was a criterion. The fiber content results in this survey may be somewhat distorted as the bobbinet, tulle, and Stabiltex choices on the survey did not specify a fiber content while the silk crepeline, polyester georgette, and nylon net did specify a fiber. Silk crepeline and Stabiltex were used most by those who stated that color was an important criteria, with tulle and nylon net again being a second choice. Stabiltex is available in a nine colors and is difficult to dye. Nylon net is available in numerous colors and is dyeable. Silk crepeline is available in only three colors but is dyeable. Tulle is available in several fiber contents, and its dyeability will be dependent on its fiber content.

Cross tabulations also compared the criteria used in making choices to the type of textile being conserved. See Table A6. Quilt Conservators working on silk quilts were concerned about sheerness, fiber content, color, hand, and strength of the sheer overlays. Those working on cotton quilts thought the same criteria were useful, but found availability to be more important than strength. Sheerness, color, fiber content, and strength were the three most important criteria for flag conservators. Costume conservators felt that sheerness, fiber content, color, and strength of the fabric were

Table A6. Responses classified by selection criteria and object conserved

	Object						
Criteria	Quilts, silk	Quilts, cotton	Flags	Costume	Upholstery	Drapery	Wall-covering
Sheerness	26	25	20	21	9	6	5
Color	23	23	16	19	8	5	5
Fiber	26	23	17	21	8	7	4
Hand	20	18	12	16	8	5	4
Availability	17	17	12	11	5	2	3
Strength	19	15	15	16	7	5	5
Dyeability	16	14	12	13	6	4	4
Weight	11	9	7	11	2	2	3
Cost	9	7	7	8	2	1	2
Tradition	5	4	3	4	2	1	2
Width	4	4	3	3	2	2	2

most important in choosing sheer overlays for their projects. Drapery, upholstery, and wall covering conservators thought that sheerness, color, fiber, hand, and strength were the most critical criteria. Weight of the sheer overlay fabric was more important to costume and silk quilt conservators than those working on other objects. The four top criteria (sheerness, fiber, color, and hand) were important to everyone, but criteria such as availability, strength, dyeability, and weight became more or less important as the object changed. Tradition and width remained of minor importance to all respondents.

Cross-tabulations compared current fabric choices with fabric choices of conservators practicing ten years ago. See Table A7. The survey format did not allow analysis of how individual conservators fabric usage habits have changed over time, but the cross tabulations indicate trends in overall fabric usage. Conservators, who used silk crepeline ten years ago, continue to favor silk crepeline overwhelmingly today. They also use Stabilitex frequently. Those who used Stabiltex ten years ago

Table A7. Fabric usage change over time

	Fabric use 10 years ago					
Fabric use today	Bobbinet	Georgette	Nylon net	Silk crepeline	Stabiltex	Tulle
Bobbinet	1	1	5	20	12	5
Georgette	1	0	6	18	13	4
Nylon net	1	1	0	14	8	0
Silk crepeline	0	1	2	1	0	1
Stabiltex	1	1	2	8	0	3
Tulle	1	2	4	16	10	0

continue to use Stabiltex and also silk crepeline. Nylon net users ten years ago continue to use nylon net, but now choose silk crepeline more than nylon net and also use Stabìltex and tulle. Conservators who used tulle ten years ago choose slightly more silk crepeline than tulle now; they also choose Stabiltex and nylon net. Those who worked with georgette ten years ago choose more silk crepeline and choose nylon net and tulle equally with georgette. Those who used bobbinet ten years ago, use slightly more silk crepeline, Stabiltex, and nylon net today and use tulle and georgette equally with the bobbinet.

The demographic data were compared to fabric choice using cross-tabulations. Fabric choice was compared to workplace, educational background, and the geographic location of each conservator's workplace.

When comparing fabric choice to workplace, conservators in private practice (30 respondents) had the most variety in their fabric choices, using all six of the fabrics. Silk crepeline was the top choice for those conservators out of the six fabrics in the survey, with Stabiltex and tulle coming in a close second and third. See Figure A6.

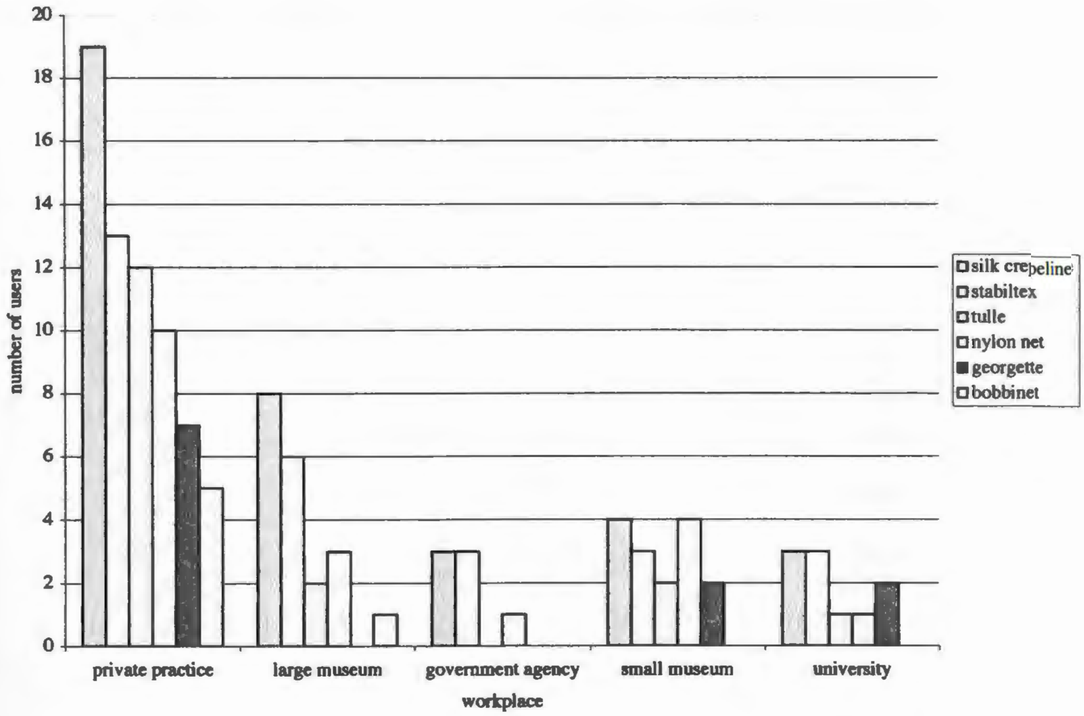

Figure A6. Fabric use by workplace

Those who worked in large museums (9 respondents) also used a variety of fabrics, choosing silk crepeline most often and not using polyester georgette at all. Those working for government agencies (5 respondents) used the smallest variety of fabrics, only selecting silk crepeline, Stabiltex, and nylon net on the survey. Nylon net and silk crepeline were the top choices for conservators working in small museums (7 respondents) and university conservators (5 respondents) used silk crepeline and Stabiltex most often.

Fabric choice by geographic location indicated that all six fabrics are used throughout the United States. See Figure A8. Results from abroad were too few to draw any conclusions. Silk crepeline was the most used overlay fabric in all four

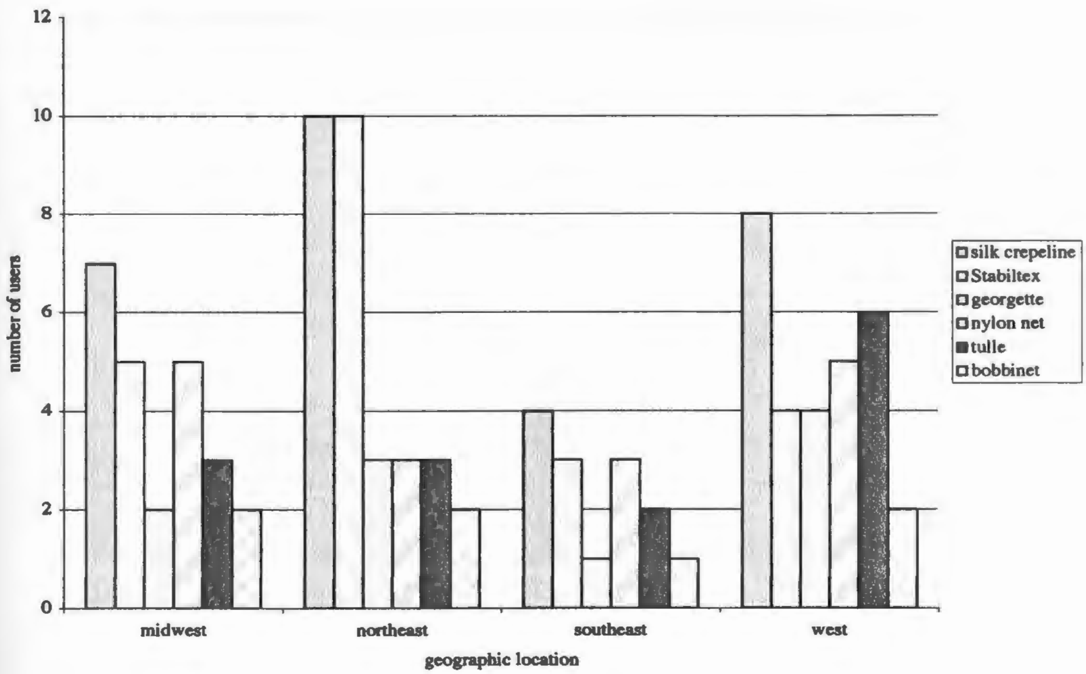

Figure A7. Fabric use by geographic location

geographic regions; bobbinet was the least used. Although the use of silk crepeline predominates in all regions, the mix of choices varies considerably across the United States.

When fabric choices were compared to educational background, silk crepeline was again the most used fabric. See Figure A9. Those conservators who trained at Universities in the United States or Canada chose silk crepeline and Stabiltex most often, but indicated that they used all six fabrics in their current practice. Self-taught conservators in the United States and Canada also chose silk crepeline most often, but tulle was their second most commonly used fabric, with nylon net coming in third. Those with a self-taught background did not use bobbinet. Those with other

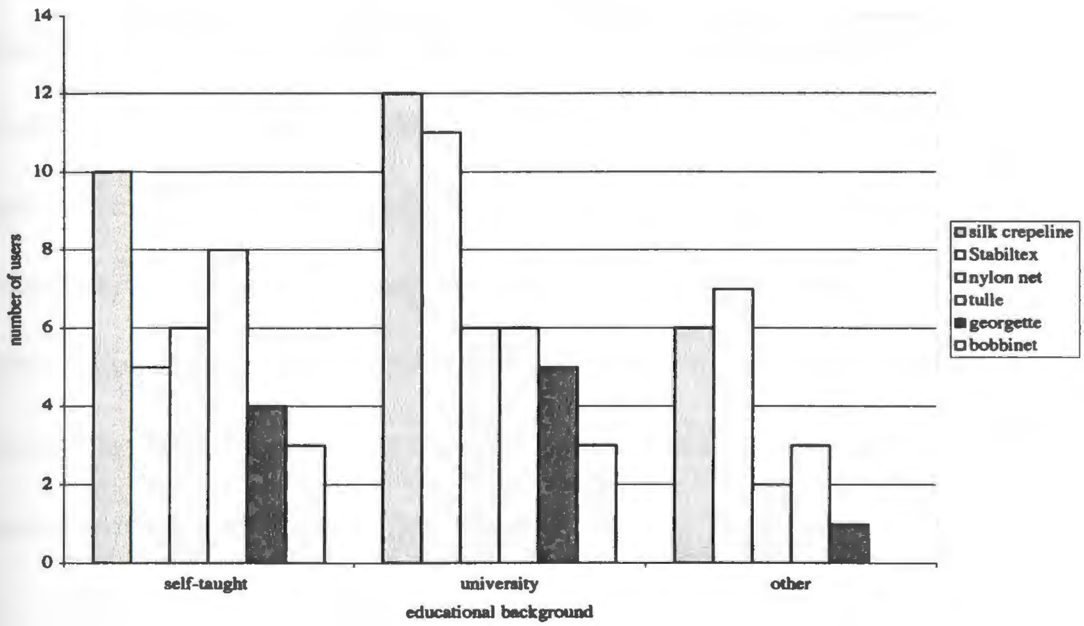

Figure A9. Fabric use by educational background

educational backgrounds including mentorships and workshops chose Stabiltex as their most commonly used fabric, with silk crepeline as their second choice. They also indicated that they use all six fabrics in their practices.

Conclusion

The purpose of the survey was to determine which sheer fabrics conservators use today and if they use adhesive, paint, or dyes to enhance their effectiveness. Forty-three conservators responded to the survey. Frequency data provide an overview of what is used, by whom, and for what objects. Insight was gained about the criteria used by conservators for choosing sheer overlay fabrics. The demographic data provide information on the respondents.

The data from the cross tabulation analysis give a broad picture of the reasons conservators choose the various sheer fabrics for their object treatments. Conservators of all types of objects showed similar rankings for the six fabrics in the survey. The top criteria used to choose sheer fabrics were similar for treating all types of objects. Sheerness, color, and fiber content were important to all conservators. Mid-level criteria showed more variety in rankings based on type of object. Strength, availability, hand, and dyeability all varied in rank with the type of object. The least used criteria remained the same for all types of objects.

Despite the small sample size, information about the fabrics chosen, the objects treated, and the criteria used for choosing those fabrics suggests the need for objective data to back up these choices. Data from this survey were used in selecting the fabrics to be tested: conservators used all six fabrics in the survey, so all six were included in the research. The tests conducted during the performance analysis section of this research were chosen to provide data relating to the criteria conservators stated that they used when choosing fabrics.

A follow-up after the initial e-mail survey announcement would have increased the response rate. An additional survey or a follow-up with more detailed questions for individual conservators designed to gather longitudinal data about changes in attitudes and use of fabrics would be useful to those developing new conservation products. Information about the practice of matching fiber content of overlays to fiber content of objects would be useful. Research on the effect of light, heat, relative humidity, and age on the sheer overlay fabrics is needed. The long-term effects of using paints and dyes with sheer overlays should be studied.

APPENDIX B

COPY OF SURVEY

SURVEY LETTER

Dear Textile Conservator/Restorer:

Your participation in this web-based survey will help increase knowledge regarding physical characteristics of conservation textiles and their use in the care of historic and fragile textile objects. Answers to the survey will be used to select the specific textiles to be used in Masters Thesis research at the University of Rhode Island. Various standardized performance tests will be conducted on the textiles selected by the survey and data will be analyzed and discussed

When you respond to the survey, your answers will go directly into a database of aggregate data. Your responses will remain anonymous, and the researchers will not be able to separate out any individual's responses to the survey. The analysis will be based on group data, and will not identify you or any individual's answers to the survey. Please feel free to contact me if you have any questions or concerns: donnalavallee@uri.edu

Thank you very much for taking the time to answer these questions.

Donna LaVallee, Textile Graduate Student, University of Rhode Island

1. Do you use sheer overlays in your conservation/restoration practice?
____ Yes – go to question 1a
____ No – go to question 8

1a. If yes, What fabrics do you use?
(check all that apply)
____ bobbinet
____ nylon net
____ polyester georgette or chiffon
____ silk crepeline
____ Stabiltex (Tetex)
____ tulle
____ other ______________________________

2. What criteria do you use to choose an overlay fabric?
(check all that apply)
____ availability
____ color
____ cost
____ dyeability
____ fiber content
____ hand
____ strength of fabric
____ tradition
____ translucency/sheerness
____ width of fabric
____ weight of fabric
____ other ________________________________

3. On what type of projects do you use overlays? (check all that apply)
____ costume or apparel
____ draperies
____ flags or banners
____ quilts, cotton
____ quilts, silk
____ upholstery
____ wall coverings
____ other ________________________________

4. Do you ever attach overlays with adhesives?
____ Yes
____ No
If yes: What type(s) or brand(s) of adhesive do you use?
____

5. Do you ever paint on top of overlays?
____ Yes
____ No
If yes: On what type of project(s) do you use paint? ________________

6. Do you ever dye an overlay fabric to match your project?
____ Yes
____ No
If yes: What percentage of your overlay projects do you dye to match?
____

7. Where you doing conservation/restoration work 10 years ago?
_____ Yes - continue
_____No – go to question 8

7a. If yes, What fabrics were you using for sheer overlays at that time?
(check all that apply)
____ bobbinet
____ nylon net
____ polyester georgette or chiffon
____ silk crepeline
____ Stabiltex (Tetex)
____ tulle
____ other ______________________

8. Describe your conservation/restoration practice?
____ governmental agency
____ large museum
____ private practice
____ regional center
____ small museum or historical society
____ university
____ other ________________

9. How did you acquire your conservation/restoration expertise?
____ self taught – U.S/Canada
____ self taught – Europe
____ university – US/ Canada
____ university – Europe
____ other institution – US/Canada
____ other institution – Europe
____ Other __________________________

10. Geographic location of your practice:
____ Asia
____ Canada
____ Europe
____ Northeast US
____ Southeast US
____ Midwest US
____ West US
____ Other __________________

11. Additional comments about the use of sheer overlays in textile conservation:

APPENDIX C

SUPPLIERS USED

Baer Fabrics
515 East Market Street
Louisville, Kentucky 40202
502-569-7012
www.baerfabrics.com

Berenstein Textiles
270 W. 39th St.
New York, New York 10018
212-354-5213
email: info@berensteintextiles.com

Fabric Place
Cowesett Corners
300 Quaker Lane
Warwick, Rhode Island 02886
401-823-5400
www.fabricplace.com

Lacis
3163 Adeline St.
Berkeley, California 94703
510-843-7178
www.lacis.com

Talas
20 West 20th Street, 5th floor
New York, New York 10011
212-219-0770
www.talasonline.com

Other Suppliers:

Farthingales
240 Wellington St.
Stratford, Ontario
Canada N5A 2L6
519-274-2374
www.farthingales.on.ca
online orders only

Testfabrics, Inc.
415 Delaware Avenue
PO Box #26
West Pittiston, Pennsylvania 18643
570-603-0432
www.testfabrics.co

APPENDIX D

GLOSSARY OF FABRIC NAMES

Bobbinet Machine knitted net with almost hexagonal meshes of twisted cotton or silk (Tortora and Merkel 1996).

Crepeline Sheer, plain weave fabric of silk or polyester (Picken 1985).

English net A net with hexagonal meshes (Tortora and Merkel 1996).

Flannel A light or medium weight fabric of plain or twill weave with a slightly napped surface (Tortora and Merkel 1996).

Georgette A lightweight, sheer plain weave fabric made of silk or manufactured fiber (Tortora and Merkel 1996).

Knotted net Large mesh net knotted by hand or on a bobbinet machine (Tortora and Merkel 1996).

Illusion A fine sheer knitted net fabric (Tortora and Merkel 1996).

Laminate A layered fabric structure wherein one or more fabrics are bonded to a continuous sheet of material, such as polyurethane foam, by heat or adhesive (Tortora and Merkel 1996).

Maline A fine, diamond shaped, open mesh knitted net made of silk, cotton or manufactured fibers (Tortora and Merkel 1996).

Muslin A firm, plain weave cotton or cotton blend fabric available in a wide-range of qualities and weights (Tortora and Merkel 1996).

Mesh A fabric characterized by open spaces between the yarns. It may be woven, knit, crocheted, knotted or lace (Tortora and Merkel 1996).

Net A general term for an open fabric formed by weaving, knitting, knotting, crocheting or twisting yarn, thread or rope together to form a meshwork (Tortora and Merkel 1996).

Nylon net A sheer knitted net made of nylon (Picken 1985).

Print cloth A plain weave cotton, rayon or blended fabric in medium weights (Tortora and Merkel 1996).

Raschel A warp knit fabric made on a Raschel machine (Tortora and Merkel 1996).

Sand-fly net A very fine mesh warp knitted net (Tortora and Merkel 1996).

Sheer A transparent or lightweight fabric such as chiffon, crepe, georgette or voile of various constructions and yarns. May be spun or filament yarn, often silk or manufactured fibers (Tortora and Merkel 1996).

Stabiltex Trade name for a sheer, plain weave polyester fabric frequently used for reinforcing and backing fragile textiles (Salik, Salik, and Salik undated).

Terelene Trade name for Stabiltex, more frequently used in Europe than the United States (Salik, Salik, and Salik undated).

Tetex Trade name for Stabiltex, more frequently used in Europe than the United States (Salik, Salik, and Salik undated).

Tricot A warp knit fabric structure. A variation of tricot fabric is an open lace-like structure (Tortora and Merkel 1996).

Tulle A warp knit net with a hexagonal mesh made of silk, cotton, or manufactured fiber (Tortora and Merkel 1996).

Velveteen A cotton or cotton-blend fabric with a short, close filling pile cut to resemble velvet (Tortora and Merkel 1996).

APPENDIX E

STATISTICAL ANALYSIS

Table E1. Descriptive Statistics - all fabrics

Property	Mean	Std. Dev	N
Thickness	9.0100	3.5900	110
Weight	0.2274	0.1392	44
Fabric Count, warp	31.9400	24.6520	55
Fabric Count, filling	32.5500	25.3480	55
Stretch, warp	29.0500	28.0090	22
Stretch, filling	40.5000	36.3720	22
Growth, warp	15.7100	17.9420	21
Growth, filling	19.7000	19.6710	20
Coefficient of friction, warp	0.3060	0.0783	33
Coefficient of friction, filling	0.2562	0.0409	33
Surface roughness, warp	10.6204	7.5883	33
Surface roughness, filling	10.0858	6.4106	33
Abrasiveness	0.7518	1.0880	99
Electrostatic cling, warp	5.0285	4.5951	33
Electrostatic cling, filling	5.9300	4.5220	33
Cover	24.8379	12.2857	33

Table E2. Fabric weight conversions

	100x100 mm	g/m²	oz/yd²	Std. Dev.
Crepeline, silk	01026	1026	0266	00039
English net, nylon	0347	347	0899	00108
English net, polyester	04599	4599	1191	00114
Georgette, polyester	04386	4386	1136	00029
Illusion, nylon	0088	88	0228	00006
Net, nylon	0118	118	0306	00022
Net, polyester	0193	193	0500	00066
Stabiltex	01281	1281	0332	00028
Tulle, cotton	03535	3535	0916	00077
Tulle, nylon	00893	893	0231	00004
Tulle, silk	01836	1836	0476	00030

Table E3. Fabric thickness conversions

	.001 inch	micron	Std. dev.
Crepeline, silk	36	9144	0346
English net, nylon	13	33020	0094
English net, polyester	1325	33655	0381
Georgette, polyester	705	17907	0158
Illusion, nylon	618	15697	0382
Net, nylon	1007	25578	0164
Net, polyester	1193	30302	0164
Stabiltex	365	9271	028
Tulle, cotton	1177	29896	0542
Tulle, nylon	63	16002	0258
Tulle, silk	123	31242	0727

Table E4. Analysis of Variance

		Sum of Squares	df	Mean Square	F	Sig.
THICK	Between Groups	1391.817	10	139.182	1044.337	.000
	Within Groups	13.194	99	.133		
	Total	1405.011	109			
WEIGHT	Between Groups	.832	10	.083	2316.516	.000
	Within Groups	.001	33	.000		
	Total	.833	43			
HPIW	Between Groups	32780.220	10	3278.022	3935.415	.000
	Within Groups	36.650	44	.833		
	Total	32816.870	54			
HPIF	Between Groups	34677.436	10	3467.744	7864.986	.000
	Within Groups	19.400	44	.441		
	Total	34696.836	54			

COVER

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4823.740	10	482.374	1680.513	.000
Within Groups	6.315	22	.287		
Total	4830.055	32			

Table E4. Analysis of Variance, continued

		Sum of Squares	df	Mean Square	F	Sig.
GROWTHF	Between Groups	7246.200	9	805.133	75.956	.000
	Within Groups	106.000	10	10.600		
	Total	7352.200	19			
BLDESLT	Between Groups	1871.696	10	187.170	.	.
	Within Groups	.000	0	.		
	Total	1871.696	10			
MIUWA	Between Groups	.184	10	.018	31.705	.000
	Within Groups	.013	22	.001		
	Total	.196	32			
SMDWA	Between Groups	1825.484	10	182.548	234.250	.000
	Within Groups	17.144	22	.779		
	Total	1842.628	32			
MIUFA	Between Groups	.045	10	.005	12.322	.000
	Within Groups	.008	22	.000		
	Total	.053	32			
SMDFA	Between Groups	1310.628	10	131.063	647.921	.000
	Within Groups	4.450	22	.202		
	Total	1315.078	32			

Table E4. Analysis of Variance, continued

		Sum of Squares	df	Mean Square	F	Sig.
GAMIUA	Between Groups	.020	10	.002	.	.
	Within Groups	.000	0	.		
	Total	.020	10			
GASMDA	Between Groups	388.762	10	38.876	.	.
	Within Groups	.000	0	.		
	Total	388.762	10			
ABRADE	Between Groups	29.830	10	2.983	3.046	.002
	Within Groups	86.178	88	.979		
	Total	116.008	98			
abrade%a	Between Groups	.000	10	.000	3.860	.000
	Within Groups	.000	88	.000		
	Total	.000	98			
STATICW	Between Groups	561.468	10	56.147	10.814	.000
	Within Groups	114.221	22	5.192		
	Total	675.689	32			
STATICF	Between Groups	529.719	10	52.972	9.351	.000
	Within Groups	124.629	22	5.665		
	Total	654.348	32			

Table E4. Analysis of Variance, continued

		Sum of Squares	df	Mean Square	F	Sig.
STIFFW1	Between Groups	59.516	10	5.952	20.581	.000
	Within Groups	34.991	121	.289		
	Total	94.507	131			
STIFFF1	Between Groups	35.338	10	3.534	11.077	.000
	Within Groups	38.600	121	.319		
	Total	73.937	131			
STRETCHW	Between Groups	16450.455	10	1645.045	738.592	.000
	Within Groups	24.500	11	2.227		
	Total	16474.955	21			
GROWTHW	Between Groups	6422.786	10	642.279	414.373	.000
	Within Groups	15.500	10	1.550		
	Total	6438.286	20			
STRETCHF	Between Groups	27672.000	10	2767.200	277.984	.000
	Within Groups	109.500	11	9.955		
	Total	27781.500	21			

Table E5. Tukey HSD – abrasion

Tukey HSD[a]

FAB	N	Subset for alpha = .05	
		1	2
3	9	.00001598	
6	9	.00008891	
4	9	.00016612	
10	9	.00026919	
7	9	.00037367	
1	9	.00045702	
9	9	.00046613	
11	9	.00082327	
2	9	.00106581	
8	9	.00123015	
5	9		.00448447
Sig.		.960	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 9.000.

Key to fabric codes for Tukey charts:

Code	Fabric
1	English Net, nylon
2	Net, nylon
3	Georgette, polyester
4	Crepeline, silk
5	Tulle, silk
6	English net, polyester
7	Illusion, nylon
8	Tulle, cotton
9	Net, polyester
10	Stabiltex, polyester
11	Tulle, nylon

Table E6. Tukey HSD – Coefficient of friction, warp

Tukey HSD[a]

FAB	N	Subset for alpha = .05			
		1	2	3	4
9	3	.185000			
8	3	.218600	.218600		
4	3	.230600	.230600	.230600	
5	3		.257367	.257367	
3	3		.268900	.268900	
10	3			.297200	
6	3				.368700
1	3				.370933
2	3				.374300
11	3				.392867
7	3				.401167
Sig.		.454	.325	.073	.843

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Table E7. Tukey HSD – Coefficient of friction, filling

Tukey HSD[a]

FAB	N	Subset for alpha = .05				
		1	2	3	4	5
9	3	.195400				
6	3	.211633	.211633			
7	3	.233633	.233633			
4	3	.245467	.245467	.245467		
8	3	.246933	.246933	.246933		
2	3	.248100	.248100	.248100		
11	3		.252367	.252367		
3	3		.257433	.257433	.257433	
1	3			.296633	.296633	.296633
5	3				.310600	.310600
10	3					.319900
Sig.		.077	.179	.094	.073	.910

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Table E8. Tukey HSD – surface roughness, warp

Tukey HSD[a]

FAB	N	Subset for alpha = .05				
		1	2	3	4	5
4	3	2.259867				
3	3	2.950933				
9	3	4.138433	4.138433			
10	3	4.486233	4.486233			
8	3		5.746433			
7	3			10.979967		
5	3			11.583267		
2	3			12.139500	12.139500	
11	3				14.591900	
1	3					23.424633
6	3					24.523300
Sig.		.132	.508	.863	.071	.896

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Table E9. Tukey HSD – surface roughness, filling

Tukey HSD[a]

FAB	N	Subset for alpha = .05						Subset for alpha = .05	
		1	2	3	4	5	6	7	8
3	3	2.227300							
10	3	3.008933	3.008933						
4	3		3.849500						
7	3			5.774967					
9	3				7.240667				
2	3					9.262567			
6	3						12.680000		
1	3						12.982867		
8	3							14.773667	
11	3							15.004500	
5	3								24.139200
Sig.		.571	.473	1.000	1.000	1.000	.999	1.000	1.000

Means for groups in homogeneous subsets are displayed.

Table E10. Tukey HSD - thickness

Tukey HSD[a]

FAB	N	Subset for alpha = .05					
		1	2	3	4	5	6
4	10	3.60					
10	10	3.65					
7	10		6.18				
11	10		6.30				
3	10			7.05			
2	10				10.07		
8	10					11.77	
9	10					11.93	
5	10					12.30	
1	10						13.00
6	10						13.25
Sig.		1.000	1.000	1.000	1.000	.057	.906

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

Table E11. Tukey HSD – weight

Tukey HSD[a]

FAB	N	Subset for alpha = .05						
		1	2	3	4	5	6	7
7	4	.087550						
11	4	.089275	.089275					
4	4		.102550					
2	4			.117925				
10	4			.128075				
5	4				.183575			
9	4				.193000			
1	4					.346925		
8	4					.353450		
3	4						.438625	
6	4							.459950
Sig.		1.000	.103	.400	.505	.895	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 4.000.

Table E12. Tukey HSD – electrostatic cling, warp

Tukey HSD[a]

FAB	N	Subset for alpha = .05			
		1	2	3	4
3	3	.0000			
8	3	.0000			
10	3	.0600	.0600		
4	3	.6233	.6233		
2	3	2.7567	2.7567	2.7567	
6	3		6.6667	6.6667	6.6667
1	3			7.7767	7.7767
7	3			8.2233	8.2233
11	3			9.2067	9.2067
5	3				10.0000
9	3				10.0000
Sig.		.911	.053	.063	.773

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Table E13. Tukey HSD – electrostatic cling, filling

Tukey HSD[a]

FAB	N	Subset for alpha = .05	
		1	2
3	3	.00	
8	3	.00	
10	3	.37	
4	3	4.39	4.39
2	3	5.39	5.39
1	3	6.67	6.67
6	3		8.36
5	3		10.00
7	3		10.00
9	3		10.00
11	3		10.00
Sig.		.067	.190

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Table E14 – Tukey HSD – stretch, warp

Tukey HSD[a]

		Subset for alpha = .05						Subset for alpha = .05	
FAB	N	1	2	3	4	5	6	7	8
4	2	1.00							
10	2	1.00							
3	2	3.00							
6	2		13.00						
1	2			22.50					
2	2			24.00	24.00				
8	2				29.50	29.50			
11	2					32.50			
9	2						42.00		
5	2							51.50	
7	2								99.50
Sig.		.941	1.000	.991	.076	.648	1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

Table E15. Tukey HSD – stretch, filling

Tukey HSD[a]

FAB	N	Subset for alpha = .05			
		1	2	3	4
3	2	2.00			
10	2	2.00			
4	2	3.00			
8	2	8.50			
5	2		34.50		
9	2		35.00		
7	2		38.00		
1	2		46.00		
2	2			78.50	
11	2				94.00
6	2				104.00
Sig.		.620	.081	1.000	.162

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

Table E16. Tukey HSD – growth, warp

Tukey HSD[a]

FABRIC	N	Subset for alpha = .05		
		1	2	3
10	2	.9652000		
3	2	1.0768350		
4	2	1.2603450		
6	2	13.135865		
2	2	19.095210		
1	2	28.771980		
11	2	36.374960	36.374960	
8	2	52.719605	52.719605	
9	2	67.095370	67.095370	
5	2		102.15016	102.15016
7	2			139.28198
Sig.		.055	.057	.549

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

Table E17. Tukey HSD – growth, filling

Tukey HSD[a]

FABRIC	N	Subset for alpha = .05					
		1	2	3	4	5	6
10	2	1.1449050					
3	2	1.4526250					
4	2	3.3649900					
8	2	16.909415	16.909415				
7	2		44.974130	44.974130			
9	2			54.177055	54.177055		
1	2			62.892690	62.892690		
5	2			66.671060	66.671060		
6	2				77.191490	77.191490	
2	2					100.60000	
11	2						164.99014
Sig.		.681	.104	.312	.253	.237	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2.000.

Table E18. Tukey HSD– cover

Tukey HSD[a]

FAB	N	Subset for alpha = .05							Subset for alpha = .05	
		1	2	3	4	5	6	7	8	9
2	3	8.115514								
11	3		13.020873							
7	3		13.786547							
9	3			19.754674						
4	3				22.430739					
10	3				23.416621	23.416621				
5	3					24.351683				
1	3						26.427460			
6	3							32.667482		
8	3								34.981376	
3	3									54.263934
Sig.		1.000	.795	1.000	.494	.566	1.000	1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

Table E19. Tukey HSD – fabric count, warp

Tukey HSD[a]

FAB	N	Subset for alpha = .05									
		1	2	3	4	5	6	7	8	9	10
2	5	8.55									
7	5		14.20								
11	5		15.60	15.60							
1	5			17.20	17.20						
6	5				18.20	18.20					
5	5					19.30					
9	5						22.30				
8	5							24.40			
10	5								60.00		
4	5									69.60	
3	5										82.00
Sig.		1.000	.375	.203	.811	.710	1.000	1.000	1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

Table E20. Tukey HSD – fabric count, filling

Tukey HSD[a]

FAB	N	Subset for alpha = .05						
		1	2	3	4	5	6	7
2	5	8.60						
5	5		15.90					
1	5		16.00					
9	5		16.60					
7	5			19.40				
11	5			19.70				
6	5			20.80				
8	5				23.50			
10	5					61.20		
4	5						76.00	
3	5							80.40
Sig.		1.000	.844	.058	1.000	1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 5.000.

Table E21. Tukey HSD – stiffness, warp

Tukey HSD[a]

FAB	N	Subset for alpha = .05				
		1	2	3	4	5
3	12	2.071				
6	12	2.179				
1	12		2.925			
8	12		2.929	2.929		
9	12		3.075	3.075	3.075	
10	12		3.083	3.083	3.083	
7	12		3.467	3.467	3.467	
4	12		3.642	3.642	3.642	
11	12			3.646	3.646	
5	12				3.671	
2	12					4.533
Sig.		1.000	.052	.052	.206	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.000.

Table E22. Tukey HSD – stiffness, filling

Tukey HSD[a]

FAB	N	Subset for alpha = .05			
		1	2	3	4
6	12	1.629			
3	12	2.142	2.142		
1	12		2.513	2.513	
7	12		2.654	2.654	
11	12		2.783	2.783	2.783
2	12			2.946	2.946
10	12			3.021	3.021
8	12			3.142	3.142
5	12			3.242	3.242
4	12			3.258	3.258
9	12				3.467
Sig.		.494	.177	.057	.116

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.000.

Table E23. Spearman's Rho Correlation Coefficients

		Abrasive-ness	Thickness	Weight	Fabric Count, warp	Fabric Count, filling	Cover	Stretch, warp	Stretch, filling
Correlation Coeff	Abrasiveness	1.000	0.107	-.0260	-0.456	-0.459	-0.404	0.634	0.409
Sig. (2-tailed)			0.293	0.089	0	0.000	0.020	0.002	0.059
N		99	99	44	55	55	33	22	22
Correlation Coeff	Thickness	0.107	1	-0.687	-0.253	-0.505	0.414	0.317	0.516
Sig. (2-tailed)		0.293		0.000	0.063	0.000	0.017	0.151	0.014
N		99	110	44	55	55	33	22	22
Correlation Coeff	Weight	-0.260	-0.687	1.000	0.376	0.155	0.825	-0.281	-0.012
Sig. (2-tailed)		0.089	0.000		0.012	0.316	0.000	0.206	0.958
N		44	44	44	44	44	33	22	22
Correlation Coeff	Fabric Count, warp	-.0456	-0.253	0.376	1.000	0.770	0.607	-0.556	-0.654
Sig. (2-tailed)		0.000	0.063	0.012		0.000	0.000	0.007	0.001
N		55	55	44	55	55	33	22	22
Correlation Coeff	Fabric Count, filling	-0.459	-0.505	0.155	0.770	1.000	0.483	-0.594	-0.785
Sig. (2-tailed)		0.000	0.000	0.316	0.000		0.004	0.004	0
N		55	55	44	55	55	33	22	22
Correlation Coeff	Cover	-0.404	0.414	0.825	0.607	0.483	1.000	-0.342	-0.343
Sig. (2-tailed)		0.020	0.017	0.000	0.000	0.004		0.12	0.118
N		33	33	33	33	33	33	22	22
Correlation Coeff	Stretch, warp	0.634	0.317	-0.281	-0.556	-0.594	-0.342	1.000	0.378
Sig. (2-tailed)		0.002	0.151	0.206	0.007	0.004	0.12		0.083
N		22	22	22	22	22	22	22	22
Correlation Coeff	Stretch, filling	0.409	0.516	-0.012	-0.785	-0.654	-0.343	0.378	1.000
Sig. (2-tailed)		0.059	0.014	0.958	0	0.001	0.118	0.083	
N		22	22	22	22	22	22	22	22

Table E23. Spearman's Rho Correlation Coefficients, continued

		Growth, warp	Growth, filing	Coeff of Friction, warp	Coeff of Friction, filling	Surface Roughness, warp	Surface Roughness, filling	Electro-static Cling, warp	Electro-static Cling, filling
Correlation Coeff	Abrasiveness	0.685	0.473	0.117	0.002	0.181	0.391	0.371	0.329
Sig. (2-tailed)		0.000	0.026	0.516	0.993	0.313	0.024	0.033	0.061
N		22	22	33	33	33	33	33	33
Correlation Coeff	Thickness	0.360	0.434	-0.041	-0.125	0.607	0.604	0.323	0.227
Sig. (2-tailed)		0.100	0.043	0.82	0.487	0.000	0.679	0.067	0.204
N		22	22	33	33	33	33	33	33
Correlation Coeff	Weight	-0.269	-0.161	-0.333	-0.047	0.126	0.075	-0.237	-.277
Sig. (2-tailed)		0.225	0.474	0.058	0.796	0.486	0.679	0.184	0.119
N		22	22	33	33	33	33	33	33
Correlation Coeff	Fabric Count, warp	-0.499	-0.815	-0.726	0.143	-0.756	-0.453	-0.537	-0.582
Sig. (2-tailed)		0.018	0.000	0.000	0.426	0.000	0.008	0.001	0.000
N		22	22	33	33	33	33	33	33
Correlation Coeff	Fabric Count, filling	-0.579	0.741	-0.292	0.038	-0.616	-0.547	-0.617	-0.525
Sig. (2-tailed)		0.005	0.000	0.000	0.834	0.000	0.001	0.000	0.002
N		22	22	33	33	33	33	33	33
Correlation Coeff	Cover	-0.277	-0.464	-0.374	0.174	-0.113	-0.015	-0.446	-0.438
Sig. (2-tailed)		0.212	0.030	0.032	0.332	0.533	0.932	0.009	0.011
N		22	22	33	33	33	33	33	33
Correlation Coeff	Stretch, warp	0.945	0.450	0.136	-0.048	0.325	0.540	0.624	0.635
Sig. (2-tailed)		0.000	0.036	0.546	0.832	0.140	0.009	0.002	0.002
N		22	22	22	22	22	22	22	22
Correlation Coeff	Stretch, filling	0.319	0.955	0.587	-0.199	0.857	0.573	0.543	0.725
Sig. (2-tailed)		0.148	0.000	0.004	0.374	0.000	0.005	0.009	0.000
N		22	22	22	22	22	22	22	22

Table E23. Spearman's Rho Correlation Coefficients, continued

		Stiffness, warp	Stiffness, filling
Correlation Coeff	Abrasiveness	0.032	0.148
Sig. (2-tailed)		0.002	0.168
N		88	88
Correlation Coeff	Thickness	-0.312	-0.587
Sig. (2-tailed)		0.003	0.000
N		88	88
Correlation Coeff	Weight	-0.779	0.715
Sig. (2-tailed)		0.000	0.533
N		44	44
Correlation Coeff	Fabric Count, warp	0.498	-0.086
Sig. (2-tailed)		0.000	0.533
N		55	55
Correlation Coeff	Fabric Count, filling	-0.488	0.083
Sig. (2-tailed)		0.000	0.546
N		55	55
Correlation Coeff	Cover	-0.799	0.429
Sig. (2-tailed)		0.000	0.13
N		33	33
Correlation Coeff	Stretch, warp	0.324	0.013
Sig. (2-tailed)		0.141	0.953
N		22	22
Correlation Coeff	Stretch, filling	0.251	-0.097
Sig. (2-tailed)		0.26	0.668
N		22	22

Table E23. Spearman's Rho Correlation Coefficients, continued

		Abrasive-ness	Thickness	Weight	Fabric Count, warp	Fabric Count, filling	Cover	Stretch, warp	Stretch, filling
Correlation Coeff	Growth, warp	0.685	0.360	-0.269	-0.499	-0.579	-0.343	0.945	0.319
Sig. (2-tailed)		0.000	0.100	0.225	0.018	0.005	0.118	0.000	0.148
N		22	22	22	22	22	22	22	22
Correlation Coeff	Growth, filling	0.409	0.434	-0.161	-0.815	-0.741	-0.374	0.450	0.955
Sig. (2-tailed)		0.059	0.043	0.474	0.000	0.000	0.032	0.036	0.000
N		22	22	22	22	22	33	22	22
Correlation Coeff	Coeff of Fric	0.117	-0.041	-0.333	-0.726	-0.192	-0.374	0.136	0.587
Sig. (2-tailed)	warp	0.516	0.82	0.058	0	0.1	0.032	0.546	0.004
N		33	33	33	33	33	33	22	22
Correlation Coeff	Coeff of Fric	0.002	-0.125	-0.047	0.143	0.038	0.174	-0.048	0.199
Sig. (2-tailed)	filling	0.993	0.487	0.796	0.126	0.834	0.332	0.832	0.374
N		33	33	33	33	33	33	22	22
Correlation Coeff	Surface	0.181	0.607	0.126	-0.456	-0.616	-0.133	0.325	0.857
Sig. (2-tailed)	Roughness	0.313	0.00	0.486	0.00	0.00	0.533	0.14	0.00
N	warp	33	33	33	33	33	33	22	22
Correlation Coeff	Surface	0.391	0.604	0.075	-0.453	-0.547	-0.150	0.54	0.573
Sig. (2-tailed)	Roughness	0.024	0.00	0.679	0.008	0.001	0.932	0.009	0.005
N	filling	33	33	33	33	33	33	22	22
Correlation Coeff	Electrostatic	0.371	0.323	-0.237	-0.537	-0.670	-0.446	0.624	0.543
Sig. (2-tailed)	Cling	0.033	0.067	0.184	0.001	0.000	0.009	0.002	0.009
N	warp	33	33	33	33	33	33	22	22
Correlation Coeff	Electrostatic	0.329	0.227	-0.277	-0.582	-0.525	-0.438	0.624	0.543
Sig. (2-tailed)	Cling	0.061	0.204	0.119	0.000	0.002	0.011	0.002	0.009
N	filling	33	33	33	33	33	33	22	22
Correlation Coeff	Stiffness	0.32	-0.312	-0.779	-0.498	-0.488	-0.799	0.324	0.251
Sig. (2-tailed)	warp	0.002	0.003	0.000	0.000	0.000	0	0.141	0.26
N		88	88	44	55	55	33	22	22
Correlation Coeff	Stiffness	0.148	-0.587	-0.715	-0.086	0.083	-0.429	-0.013	0.097
Sig. (2-tailed)	filling	0.168	0.000	0.000	0.533	0.546	0.013	0.953	0.668
N		88	88	44	55	55	33	22	22

Table E23. Spearman's Rho Correlation Coefficients, continued

	Growth, warp	Growth, filing	Coeff of Friction, warp	Coeff of Friction, filling	Surface Roughness, warp	Surface Roughness, filling	Electro-static Cling, warp	Electro-static Cling, filling
Growth, warp	1.000	0.386	0.016	-0.014	0.295	0.601	0.601	0.624
		0.076	0.942	0.950	0.182	0.003	0.003	0.002
	22	22	22	22	22	22	22	22
Growth, filling	0.386	1.000	0.59	-0.048	0.826	0.654	0.585	0.696
	0.076		0.004	0.832	0.000	0.001	0.004	0.000
	22	22	22	22	22	22	22	22
Coeff of Fric	0.016	0.016	1.000	0.098	0.631	0.11	0.286	0.33
warp	0.942	0.942		0.589	0.000	0.543	0.107	0.061
	22	22	33	33	33	33	33	33
Coeff of Fric	-0.014	-0.048	0.098	1.000	0.008	0.083	-0.149	-0.187
filling	0.950	0.832	0.589		0.963	0.648	0.407	0.298
	22	22	33	33	33	33	33	33
Surface	0.295	0.826	0.631	0.008	1.000	0.662	0.473	0.446
Roughness	0.182	0.000	0.000	0.963		0.000	0.005	0.009
warp	22	22	33	33	33	33	33	33
Surface	0.601	0.654	0.11	0.662	0.662	1.000	0.446	0.407
Roughness	0.003	0.001	0.543	0.000	0.000		0.009	0.019
filling	22	22	33	33	33	33	33	33
Electrostatic	0.601	0.585	0.286	0.473	0.446	0.446	1.000	0.725
Cling	0.003	0.004	0.107	0.005	0.009	0.009		0.000
warp	22	22	33	33	33	33	33	33
Electrostatic	0.624	0.696	0.33	0.446	0.407	0.407	0.725	1.000
Cling	0.002	0.000	0.061	0.009	0.019	0.019	0.000	
filling	22	22	33	33	33	33	33	33
Stiffness	0.334	0.268	0.174	0.054	0.021	0.23	0.314	0.352
warp	0.139	0.253	0.334	0.767	0.908	0.198	0.075	0.044
	21	20	33	33	33	33	33	33
Stiffness	0.027	0.003	0.253	0.315	-0.076	0.077	-0.130	-0.054
filling	0.908	0.991	0.156	0.074	0.673	0.672	0.372	0.763
	21	20	33	33	33	33	33	33

Table E23. Spearman's Rho Correlation Coefficients, continued

		Stiffness, warp	Stiffness, filling
Correlation Coeff	Growth, warp	0.334	0.027
Sig. (2-tailed)		0.139	0.908
N		21	21
Correlation Coeff	Growth, filling	0.268	-0.003
Sig. (2-tailed)		0.253	0.991
N		20	20
Correlation Coeff	Coeff of Fric	0.174	0.253
Sig. (2-tailed)	warp	0.334	0.156
N		33	33
Correlation Coeff	Coeff of Fric	0.054	0.315
Sig. (2-tailed)	filling	0.767	0.74
N		33	33
Correlation Coeff	Surface	0.021	0.076
Sig. (2-tailed)	Roughness	0.908	0.673
N	warp	33	33
Correlation Coeff	Surface	0.23	0.077
Sig. (2-tailed)	Roughness	0.198	0.672
N	filling	33	33
Correlation Coeff	Electrostatic	0.314	-0.060
Sig. (2-tailed)	Cling	0.075	0.742
N	warp	33	33
Correlation Coeff	Electrostatic	0.352	-0.054
Sig. (2-tailed)	Cling	0.044	0.763
N	filling	33	33
Correlation Coeff	Stiffness	1.000	1.000
Sig. (2-tailed)	warp		
N		88	88
Correlation Coeff	Stiffness	1.000	1.000
Sig. (2-tailed)	filling		
N		88	88

APPENDIX F

RAW DATA

Table F1. Raw data - abrasiveness

Fabric	Amount of fiber (mm)	Cover (% area)
English Net, nylon	0.08604	26.46180
	1.95895	26.35299
	0.22100	26.46759
	0.04622	
	0.83507	
	1.50413	
	0.79559	
	0.80774	
	0.59518	
mean	0.76110	26.42746
Net, nylon	1.64078	8.37472
	0.18827	7.75933
	3.34938	8.21249
	0.08064	
	0.71495	
	3.72693	
	0.87083	
	1.35365	
	4.05050	
mean	1.77510	8.11551
Georgette, polyester	0.00000	54.23218
	0.02396	55.04183
	0.00000	53.51780
	0.00000	
	0.00000	
	0.00000	
	0.00000	
	0.00000	
	0.00000	
mean	0.00266	54.26393
Crepeline, silk	0.11775	22.87810
	0.00000	21.06947
	0.16634	23.34465
	0.00000	
	0.00000	
	0.00000	
	0.00000	
	0.00000	
	2.20255	
mean	0.27629	22.43074
Tulle, silk	0.04960	23.85534
	4.69595	23.93901
	0.91233	25.26070
	2.14924	
	0.08300	
	0.00000	
	0.00000	
	3.03121	
	0.00000	
mean	1.21348	24.35168
English net, polyester	0.00000	32.87095
	0.23146	32.62810
	0.00000	32.50340
	0.59113	
	0.00000	
	0.00000	
	0.15105	
	0.00000	
	0.00000	
mean	0.10818	32.66748

Fabric	Amount of fiber (mm)	Cover (% area)
Illusion, nylc	1.02637	13.84069
	0.47304	13.50004
	0.75139	14.01891
	0.37317	
	0.27195	
	0.74329	
	0.17781	
	0.87960	
	0.90457	
mean	0.62235	13.78655
Tulle, cotton	0.89175	34.82143
	0.76573	35.05272
	0.94276	35.06999
	0.55435	
	3.74684	
	1.45555	
	0.55609	
	2.12225	
	2.40398	
mean	1.49326	34.98138
Net, polyeste	3.36794	19.82038
	0.35630	20.02570
	1.30675	19.41794
	0.19704	
	0.00000	
	0.28645	
	0.44947	
	0.00000	
	0.08840	
mean	0.67248	19.75467
Stabiltex	0.14441	23.76330
	0.00000	23.16036
	2.46978	23.32620
	0.04116	
	0.03239	
	0.00000	
	0.00000	
	0.03860	
	0.03595	
mean	0.30692	23.41662
Tulle, nylon	3.77889	13.24042
	0.58370	12.68314
	0.68807	13.13906
	0.77940	
	0.61913	
	0.51358	
	0.14171	
	0.10966	
	2.12630	
mean	1.03783	13.02087

Table F2. Raw data – coefficient of friction

Fabric	Warp	Filling	Grand average
English Net, nylon	0.3628	0.3202	0.3338
	0.3837	0.2758	
	0.3663	0.2939	
mean	0.371	0.2967	0.3338
Net, nylon	0.427	0.2601	0.3112
	0.3728	0.2423	
	0.3231	0.2419	
mean	0.3743	0.2481	0.3112
Georgette, polyester	0.2455	0.2469	0.2632
	0.2974	0.2572	
	0.2638	0.2682	
mean	0.2689	0.2574	0.2632
Crepeline, silk	0.2361	0.2281	0.238
	0.2352	0.2504	
	0.2205	0.2579	
mean	0.2306	0.2455	0.238
Tulle, silk	0.2507	0.3089	0.284
	0.2521	0.3298	
	0.2693	0.2931	
mean	0.2574	0.3106	0.284
English net, polyester	0.3636	0.2364	0.2902
	0.3795	0.2000	
	0.3630	0.1985	
mean	0.3687	0.2116	0.2902
Illusion, nylon	0.4038	0.2580	0.3174
	0.3853	0.2210	
	0.4144	0.2219	
mean	0.4012	0.2336	0.3174
Tulle, cotton	0.2148	0.2549	0.2328
	0.2217	0.2433	
	0.2193	0.2426	
mean	0.2186	0.2469	0.2328
Net, polyester	0.1629	0.1811	0.1902
	0.1935	0.1798	
	0.1986	0.2253	
mean	0.1850	0.1954	0.1902
Stabiltex	0.2859	0.3057	0.3086
	0.2652	0.3284	
	0.3405	0.3256	
mean	0.2972	0.3199	0.3086
Tulle, nylon	0.4144	0.2513	0.3226
	0.3929	0.2841	
	0.3713	0.2217	
mean	0.3929	0.2524	0.3226

Table F3. Raw data – surface roughness

Fabric	Warp*	Filling*	Grand average
English Net, nylon	24.0591	12.8801	18.2037
	22.3382	13.0773	
	23.8766	12.9912	
mean	23.4246	12.9829	18.2037
Net, nylon	11.8189	8.6702	10.701
	11.9544	9.6603	
	12.6452	9.4572	
mean	12.1395	9.2626	10.701
Georgette, polyester	3.4625	1.9248	2.5891
	2.8763	2.045	
	2.514	2.7121	
mean	2.9509	2.2273	2.5891
Crepeline, silk	2.4229	3.5799	3.0547
	2.36	4.165	
	1.9967	3.8036	
mean	2.2599	3.8495	3.0547
Tulle, silk	11.4676	24.3677	17.8613
	11.9466	23.6265	
	11.3356	24.4234	
mean	11.5833	24.1392	17.8613
English net, polyester	22.3874	12.3997	18.6016
	25.4073	13.1018	
	25.7752	12.5385	
mean	24.5233	12.6800	18.6016
Illusion, nylon	11.1619	5.8693	8.3775
	10.6286	5.6825	
	11.1494	5.7731	
mean	10.9800	5.7750	8.3775
Tulle, cotton	6.5289	15.3691	10.26
	5.5611	14.2068	
	5.1493	14.7451	
mean	5.7464	14.7737	10.26
Net, polyester	3.874	7.325	5.6895
	4.0423	6.7978	
	4.499	7.5992	
mean	4.1384	7.2407	5.6895
Stabiltex	3.7207	3.0286	3.7476
	5.1454	3.7803	
	4.5926	2.2179	
mean	4.4862	3.0089	3.7476
Tulle, nylon	12.8978	15.2378	14.7982
	14.9153	15.3053	
	15.9626	14.4704	
mean	14.5919	15.0045	14.7982

* surface roughness is reported in microns

Table F4. Raw data – electrostatic cling

Fabric	Warp*	Filling*
English Net, nylon	3.33	10
	10	10
	10	0
mean	7.78	6.67
Net, nylon	3.4	5.05
	4.1	7.05
	0.77	4.08
mean	2.76	5.39
Georgette, polyeste	0	0
	0	0
	0	0
mean	0	0
Crepeline, silk	0.6	0
	0.72	4.57
	0.55	8.6
mean	0.62	4.39
Tulle, silk	10	10
	10	10
	10	10
mean	10	10
English net, polyest	0	10
	10	10
	10	5.08
mean	6.67	8.36
Illusion, nylon	6.07	10
	10	10
	8.6	10
mean	8.22	10
Tulle, cotton	0	0
	0	0
	0	0
mean	0	0
Net, polyester	10	10
	10	10
	10	10
mean	10	10
Stabiltex	0.03	0.57
	0.05	0
	0.1	0.55
mean	0.06	0.37
Tulle, nylon	10	10
	10	10
	7.62	10
mean	9.21	10

* cling time is reported in minutes

Table F5. Raw data - fabric stretch and growth, warp

	Warp			
Fabric	Stretch (mm)	Growth (mm)	% stretch	% growth
English Net,	54.615	28.398	22	11
nylon	57.557	29.146	23	12
mean	56.086	28.772	22	12
Net, nylon	56.821	16.860	23	7
	61.474	21.331	25	9
mean	59.148	19.095	24	8
Georgette,	7.610	1.199	3	0
polyester	6.823	0.955	3	0
mean	7.217	1.077	3	0
Crepeline,	3.144	1.254	1	1
silk	3.629	1.267	1	1
mean	3.387	1.260	1	1
Tulle, silk	121.750	100.359	49	40
	135.010	103.941	54	42
mean	128.380	102.150	51	41
English net,	32.305	12.778	13	5
polyester	32.216	13.494	13	5
mean	32.261	13.136	13	5
Illusion, nylon	246.232	178.464	98	71
	253.808	broke	101	broke
mean	250.020	89.232	100	71
Tulle, cotton	69.495	46.931	28	19
	78.446	58.508	31	23
mean	73.970	52.720	30	21
Net, polyester	105.062	68.823	42	28
	105.103	65.368	42	26
mean	105.082	67.095	42	27
Stabiltex	3.460	1.551	1	1
	3.673	0.379	1	0
mean	3.566	0.965	1	0
Tulle, nylon	82.718	37.711	33	15
	79.771	35.039	32	14
mean	81.244	36.375	32.5	14.5

Table F6. Raw data - fabric stretch and growth, filling

	Filling			
Fabric	Stretch (mm)	Growth (mm)	% stretch	% growth
English Net,	113.439	62.568	45	25
nylon	116.860	63.218	47	25
mean	115.149	62.893	46	25
Net, nylon	200.198	broke	80	broke
	191.437	broke	77	broke
mean	195.817		78.5	
Georgette,	5.252	1.772	2	1
polyester	5.073	1.133	2	0
mean	5.163	1.453	2	1
Crepeline,	8.649	3.376	3	1
silk	7.352	3.354	3	1
mean	8.000	3.365	3	1
Tulle, silk	77.051	57.747	31	23
	95.621	75.595	38	30
mean	86.336	66.671	34.5	26.5
English net,	259.335	78.682	103	31
polyester	262.521	75.701	105	30
mean	260.928	77.191	104	31.5
Illusion, nylon	82.478	29.861	43	24
	107.472	60.088	33	12
mean	94.975	44.974	38	18
Tulle, cotton	20.933	18.035	8	6
	21.855	15.784	9	6
mean	21.394	16.909	8.5	6
Net, polyester	83.039	50.973	33	23
	91.468	57.381	37	23
mean	87.254	54.177	35	23
Stabiltex	4.563	1.397	2	1
	4.553	0.893	2	0
mean	4.558	1.145	2	0
Tulle, nylon	228.468	158.903	91	64
	243.469	171.077	97	68
mean	235.969	164.990	94	66

Table F7. Raw data - thickness and weight

Fabric	Thickness (0.001inch)	Weight (gm per 10cm sq)
English Net, nylon	13	0.3484
	13	0.3616
	13	0.3404
	13	0.3373
	13	
	13	
	12.8	
	13	
	13.2	
	13	
mean	13	0.3469
Net, nylon	10	0.1153
	10	0.118
	10.5	0.1178
	10	0.1206
	10	
	10	
	10.2	
	10	
	10	
	10	
mean	10.07	0.1179
Georgette, polyeste	7	0.4345
	7	0.4391
	7	0.4411
	7	0.4398
	7	
	7	
	7	
	7	
	7	
	7.5	
mean	7.05	0.4386
Crepeline, silk	4	0.1057
	3.8	0.1061
	3.5	0.0991
	3	0.0993
	3.5	
	4	
	3.2	
	3.5	
	3.5	
	4	
mean	3.6	0.1026
Tulle, silk	13	0.1835
	12	0.1798
	12.2	0.1838
	12	0.1872
	13.3	
	13	
	13	
	11.2	
	11.8	
	11.5	
mean	12.3	0.1836
English net, polyest	13	0.4545
	13	0.4528
	13.8	0.4556
	14	0.4769
	13	
	13.2	
	13	
	13	
	13	
	13.5	
mean	13.25	0.4600

Fabric	Thickness (0.001inch)	Weight (gm per 10cm sq)
Illusion, nylon	6	0.0866
	7	0.088
	6	0.088
	6.8	0.0876
	6	
	6	
	6	
	6	
	6	
	6	
mean	6.18	0.0876
Tulle, cotton	12	0.356
	12	0.3632
	12.8	0.347
	12	0.3476
	11	
	12	
	11.2	
	11.5	
	11.2	
	12	
mean	11.77	0.3535
Net, polyester	11.5	0.1862
	12	0.1919
	12	0.1918
	12	0.2021
	12	
	12	
	12	
	12	
	12	
	11.8	
mean	11.93	0.1930
Stabiltex	3.5	0.1255
	3.5	0.1268
	4	0.132
	3.2	0.128
	4	
	3.8	
	3.5	
	3.5	
	3.5	
	4	
mean	3.65	0.1281
Tulle, nylon	6.5	0.0898
	6.5	0.0891
	6	0.089
	6	0.0892
	6	
	6	
	6.5	
	6.5	
	6.5	
	6.5	
mean	6.3	0.0893

Table F8. Raw data - stiffness

	Bending Length (cm)			Bending Length (cm)			Bending Length (cm)	
Fabric	warp	filling	Fabric	warp	filling	Fabric	warp	filling
English Net, nylon	2.8	2.4	Tulle, silk	3.5	3.5	Net, polyester	4.85	4.05
	2.8	2.1		3.3	2.8		3.6	4.15
	2.9	3.6		3.75	2.9		2.6	2.7
	3.1	2.5		3.25	2.9		2.3	2.45
	2.95	2.5		3.75	2.75		2.35	3.25
	2.9	2.5		3.4	2.8		1.75	2.25
	3.15	2.45		4.3	3.55		3.7	4.7
	3.25	2.95		3.45	3.1		4.05	4.45
	2.85	2.35		3.9	3.35		3.55	3.2
	2.85	2.3		4.35	3.2		4	2.4
	2.75	2.1		3.3	3.85		2.25	4
	2.8	2.4		3.8	4.2		1.9	4
mean	2.925	2.5125	mean	3.6708	3.2417	mean	3.075	3.4667
Net, nylon	3.5	1.9	net, polyester	2	1.5	Stabiltex	3	3
	4.65	2.6		2	1.6		2.25	3.75
	4.6	2.6		2	1.55		3.45	2.85
	4.55	2.6		2.15	1.7		2.95	3.2
	4.75	2.75		2.85	1.55		3.75	2.75
	4.2	2.2		2.25	1.75		3.05	3
	4.6	3.25		2.2	1.7		2.6	2.95
	4.95	3		2.1	1.7		3.1	3.05
	3.6	3.2		2.15	1.65		3.6	3
	3.6	3.6		2.05	1.6		3.5	2.7
	5.4	3.75		2.35	1.7		2.85	3
	6	3.9		2.05	1.55		2.9	3
mean	4.5333	2.9458	mean	2.1792	1.6292	mean	3.08333	3.02083
Georgette, polyester	2.1	2	Illusion, nylon	2.4	1.6	Tulle, nylon	2.9	3.15
	1.95	2.15		2.25	2.15		3	3.4
	1.85	2.2		4.15	3.7		3.95	1.9
	2.05	1.95		4.2	3.55		4.1	2
	2.2	2.2		2.7	1.8		4.45	1.95
	2.2	2.2		3.45	2.25		4.25	2.25
	2	2.15		4.1	3.2		3.25	3.2
	1.9	2.1		3.65	3		3.3	3.65
	2.2	2.2		3.6	2		3.15	3.6
	2.4	2.1		2.95	1.85		3	4.6
	2.2	2.25		4.4	3.25		4.2	1.5
	1.8	2.2		3.75	3.5		4.2	2.2
mean	2.0708	2.1417	mean	3.4667	2.6542	mean	3.6458	2.7833
Crepeline, silk	3.4	3.25	Tulle, cotton	2.95	2.5			
	3.25	2.45		3.2	3.8			
	4.7	3.55		3.2	2.95			
	3.3	3.45		3.1	3.35			
	4	2.6		2.75	3.4			
	3.7	2.85		3.2	2.75			
	3	3.9		2.85	3.55			
	3	3.9		2.95	3.65			
	3.6	3.7		3.1	2.5			
	4	2.95		2.55	2.95			
	3.75	3.4		2.5	3.3			
	4	3.1		2.8	3			
mean	3.6417	3.2583	mean	2.9292	3.1417			

Table F9. Raw data - cover and gloss

Fabric	Cover (% area)	Gloss Degree %	Fabric	Cover (% area)	Gloss Degree %
English Net, nylon	26.46180	12.49	Illusion, nylon	13.84069	7.43
	26.35299			13.50004	
	26.46759			14.01891	
mean	26.42746		mean	13.78655	
Net, nylon	8.37472	11.42	Tulle, cotton	34.82143	4.13
	7.75933			35.05272	
	8.21249			35.06999	
mean	8.11551		mean	34.98138	
Georgette, polyester	54.23218	11.30	Net, polyester	19.82038	7.67
	55.04183			20.02570	
	53.51780			19.41794	
mean	54.26393		mean	19.75467	
Crepeline, silk	22.87810	15.21	Stabiltex	23.76330	26.43
	21.06947			23.16036	
	23.34465			23.32620	
mean	22.43074		mean	23.41662	
Tulle, silk	23.85534	8.54	Tulle, nylon	13.24042	8.91
	23.93901			12.68314	
	25.26070			13.13906	
mean	24.35168		mean	13.02087	
English net, polyester	32.87095	11.54			
	32.62810				
	32.50340				
mean	32.66748				

Table F10. Raw data - fabric count

Fabric	Warp*	Filling*	Fabric	Warp*	Filling*
English Net,	17.0	16.0	Illusion, nylon	13.5	21.0
nylon	16.0	17.0		14.0	20.0
	18.0	15.0		14.0	19.0
mean	17.0	16.0	mean	13.8	20.0
Net, nylon	8.0	8.5	Tulle, cotton	23.5	23.5
	9.0	8.5		25.0	24.0
	8.5	8.5		24.5	23.5
mean	8.5	8.5	mean	24.3	23.7
Georgette,	80.0	80.0	Net, polyester	22.0	16.0
polyester	84.0	80.0		23.0	16.0
	80.0	80.0		22.0	17.5
mean	81.3	80.0	mean	22.3	16.5
Crepeline,	70.0	76.0	Stabiltex	60.0	62.0
silk	70.0	76.0		60.0	62.0
	70.0	76.0		60.0	60.0
mean	70.0	76.0	mean	60.0	61.3
Tulle, silk	19.0	16.0	Tulle, nylon	17.0	19.5
	19.5	16.0		16.0	20.0
	19.0	16.0		17.0	20.0
mean	19.2	16.0	mean	16.7	19.8
English net,	18.0	21.0			
polyester	18.0	21.0			
	18.0	20.0			
mean	18.0				

Note: wovens are counted as yarns per inch; knits as hex per inch

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